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Department of
Water Resources

save water
DWR

Evaluation of Ground Water Resources: Sonoma County

Department of Water Resources
in cooperation with the County of Sonoma

Bulletin 118-4
February 1982

ON THE COVER View to the northwest fror Adobe Canyon Road across the northern end c the Sonoma Valley study area In many areas c Sonoma County, vineyards are both irrigate and protected from frost by ground wate pumped through a sprinkler irrigation system.

Department of Water Resources
in cooperation with the
County of Sonoma

Bulletin 118-4

Evaluation of Ground Water Resources: Sonoma County

Volume 4: Sonoma Valley

February 1982

Huey D. Johnson
Secretary for Resources

Edmund G. Brown Jr.
Governor

Ronald B. Robie
Director

The Resources Agency

State of California

Department of Water Resources

CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

NOTE: Customary and metric values are shown to the same degree of accuracy.

FOREWORD

Ground water plays an important role in Sonoma County. As the population of this North Bay county has increased over the last 30 years, the use of ground water has likewise increased. Currently, over 15,000 wells have been identified in the county. These wells are used for domestic and agricultural purposes in rural areas, and for municipal and industrial purposes in urban areas.

The Sonoma County Water Agency (SCWA) requested the California Department of Water Resources (DWR) to undertake a cooperative study to estimate the volume of ground water in storage and the recharge potential in the Santa Rosa Plain, Petaluma Valley, Sonoma Valley, and Alexander Valley and Healdsburg area. The study examined alternative ways the ground water resources of the county may be used conjunctively with the Russian River and other surface water sources.

The results of the study are presented in four volumes. This report is Volume 4 and describes ground water conditions in the Sonoma Valley. Volume 2 deals with the Santa Rosa Plain, Volume 3 with the Petaluma Valley, and Volume 5 with the Alexander Valley and Healdsburg area. The present study is designed to augment the earlier county-wide investigation of geology and hydrology conducted jointly by the Sonoma County Planning Department and DWR. Results of the earlier investigation were published as DWR Bulletin 118-4, Volume 1 (Ford, 1975).

This report on the Sonoma Valley includes an evaluation of geologic and hydrologic characteristics of the ground water basin, an evaluation of the volume of usable ground water in the basin and the volume that can reasonably be extracted, possible changes in water quality resulting from pumping of ground water, an evaluation of the interconnection of ground and surface water, and the potential for artificial recharge of the ground water basin.

Ronald B. Robie

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

PLATE

(in separate pocket)

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by the following:

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Department of Water Resources
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The California Water Commission serves as a policy advisory body to the Director of Water Resources on all California water resources matters. The nine-member citizen commission provides a water resources forum for the people of the State, acts as a liaison between the legislative and executive branches of State Government, and coordinates Federal, State, and local water resources efforts.

Chapter 1. INTRODUCTION

The Sonoma Valley (Figures 1 and 2), while not experiencing as rapid growth as some other areas in Sonoma County, has been affected by the general population increase of the North Bay area. As the population has increased, so has the demand for water. Ground water, water stored underground in the spaces between grains of sand and gravel and in cracks in consolidated rocks, plays an important role in meeting this demand.

The City of Sonoma has grown 42 percent over the last 10 years to 6,059. In the same period of time, Oakmont, a community northwest of Kenwood, has doubled in size. Although these communities and most others in the Sonoma Valley receive surface water from the Russian River, many new homes are being sited in rural areas where a private well is the only water source. In addition, six mutual water companies and nine small commercial and mobile home park systems that rely on ground water are scattered throughout the Sonoma Valley.

To offer some ideas on possible conjunctive use of ground and surface water, this study evaluates the hydrologic characteristics of this rapidly growing area and the effects of increased use on the ground water resource.

The Sonoma Valley, numbered 2-2.02 in California Department of Water Resources (DWR) Bulletin 118 (California Department of Water Resources, 1975), is included in the present study area. The Kenwood Valley basin, numbered 2-19 in the same report, is also included in the present study area. Both valleys have been included with other areas in the County in the Sonoma County Basin (Peters, 1980).*

Location of Study Area

The study area encompasses 41 700 hectares (103,000 acres)** extending from Melita south to San Pablo Bay (Figure 2). The area extends west to the crest of the Sonoma Mountains, which separate the Petaluma and Sonoma Valleys; it extends east to the Sonoma/Napa County line. The "Bennett Mountain area" referred to in this report is the area extending from Melita east to the surface water divide northwest of Kenwood, and the southeastern half of Bennett Valley. The rest of the study area is referred to as the "Sonoma Valley area". Unless otherwise noted in the text, "Sonoma Valley" includes both the Sonoma Valley study area and the Bennett Mountain area.

Method of Investigation

To simplify compilation and evaluation of hydrologic data for computer analysis, the study area has been divided along township, range, and section lines to form 189 cells of 130 or 260 hectares (320 or 640 acres) each. All hydrologic parameters, such as ground water levels, have been evaluated using these cell divisions.

Basic data available for the Sonoma Valley were compiled and evaluated in several different ways. Water well logs were used to develop geologic cross sections showing the subsurface geology. The well log information on types of materials encountered in each well was coded as input to the TRANSCAP computer program. This program averages the log information by cells to determine estimates of the total ground water storage

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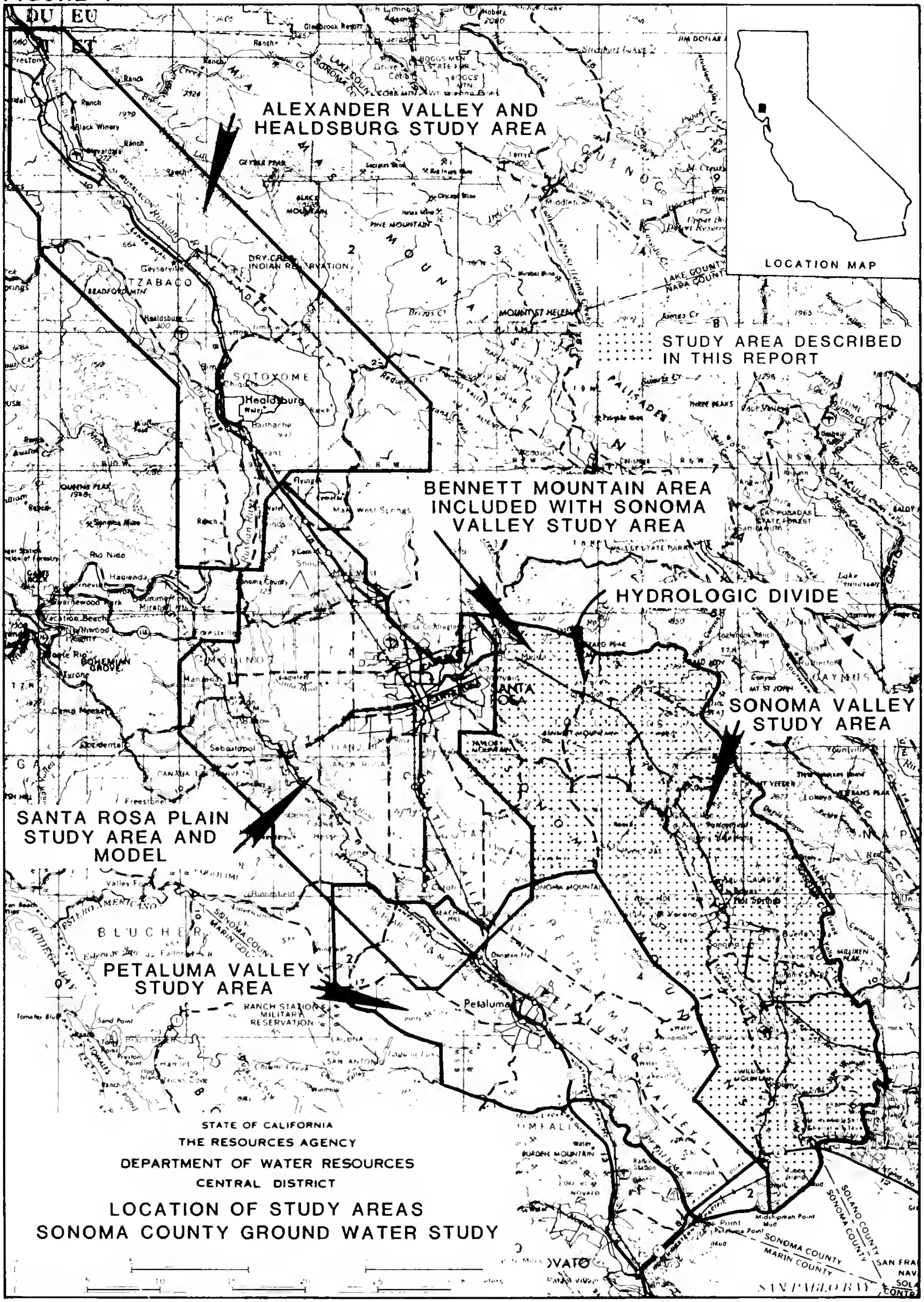
* A list of references is presented following Chapter 8.

**Conversion factors for changing from metric to customary units are listed inside the back cover.

FIGURE 1


ALEXANDER VALLEY AND
HEALDSBURG STUDY AREA
LOCATION MAP
STUDY AREA DESCRIBED
IN THIS REPORT
BENNETT MOUNTAIN AREA
INCLUDED WITH SONOMA
VALLEY STUDY AREA
HYDROLOGIC DIVIDE
SONOMA VALLEY
STUDY AREA
SANTA ROSA PLAIN
STUDY AREA AND
MODEL
PETALUMA VALLEY
STUDY AREA
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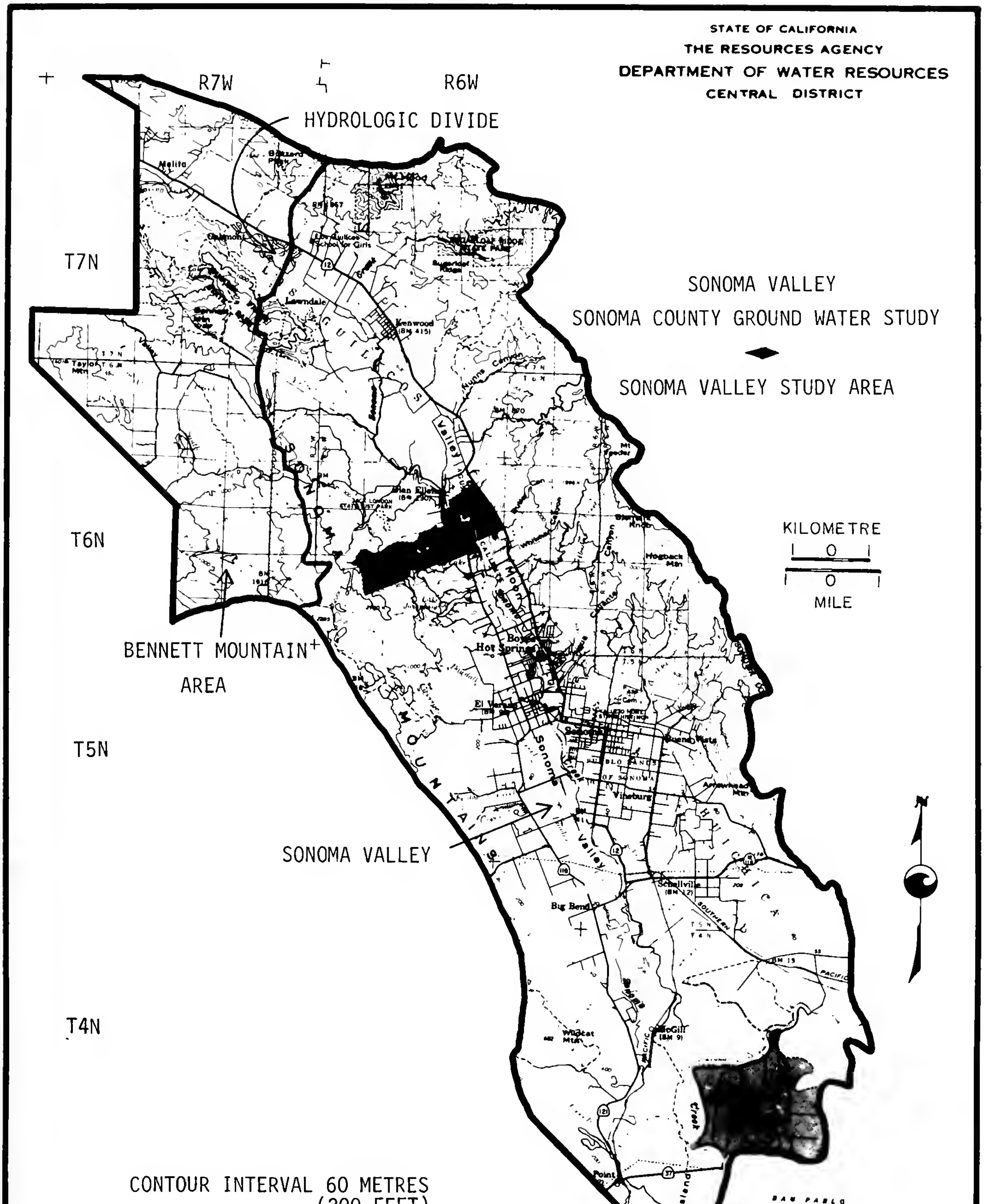
LOCATION OF STUDY AREAS
SONOMA COUNTY GROUND WATER STUDY


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY
SONOMA VALLEY STUDY AREA
R7W
R6W
T7N
T6N
T5N
T4N
HYDROLOGIC DIVIDE
BENNETT MOUNTAIN AREA
SONOMA VALLEY
STUDY AREA BOUNDARY
KILOMETRE
0
MILE
CONTOUR INTERVAL 60 METRES (200 FEET)
Melita
Kenwood
Glen Ellen
Lawndale
Boyes Hot Springs
El Verano
Vineburg
Schellville
Big Bend
Wildcat Mtn
Hogback Mtn
Arrowhead Mtn
Tubbs Island
SAN PABLO BAY
SONOMA MOUNTAINS

capacity for each cell. When combined with fall 1980 water level information, the total volume of ground water in storage and the total storage space available to receive recharge were determined, assuming that all ground water in the study area is unconfined.

All available water quality data were tabulated and plotted on topographic maps. This information was evaluated to determine regional water quality types as an indicator of aquifer continuity. Special water quality problems such as high sodium and salinity were evaluated to determine areal extent, source, and potential for migration of the affected water.

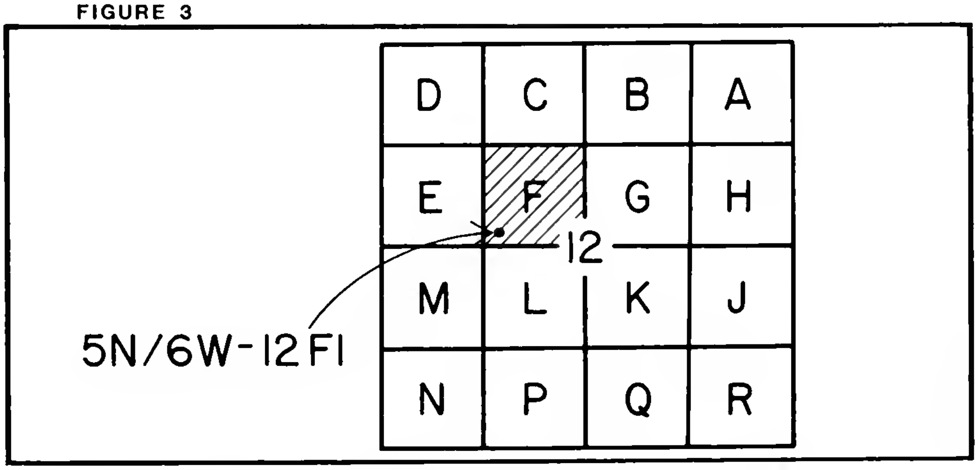
Soil maps developed by the U. S. Department of Agriculture Soil Conservation Service (Miller, 1972) were used to classify lands according to slope and soil infiltration rate. Those soils on slopes of less than 15 percent and with an infiltration rate greater than 1.55 centimetres (0.6 inch) per hour have been tentatively classified as ground water recharge areas (after Muir and Johnson, 1979).

Data from the investigation were insufficient to provide accurate estimates of the annual quantity of ground water recharge in the Sonoma Valley. Some suggestions for a data collection program to determine this rate are included in this report (see Chapter 8).

The water well numbering system used in this bulletin is based on the rectangular system of subdivision of public land. When Sonoma County was first settled, most valley lands became parts of 25 land-grant ranchos. Lands outside of the land grants became public lands and were surveyed into townships of 93 square kilometres (36 square miles) that were referenced to the Mount Diablo base and meridian. Each township was divided into 36 sections of roughly 2-1/2 square kilometres (one square mile) each. Because land-grant areas do not have surveyed township, range, and section lines, these have been projected for the purpose of numbering water wells.

A State well number has two basic parts: its township location and its section location. For example, Well 5N/6W-12F1 is located in Township 5 North, Range 6 West, and Section 12; this places the well immediately west of the City of Sonoma. Each section is subdivided into 16 quarter-quarter sections of 16 hectares (40 acres) each; each 16-hectare tract is identified by a letter. Letters A through R are used, with letters I and O omitted to avoid confusion with similar appearing numbers. This particular well is in Tract "F", which can also be described as the southeast quarter of the northwest quarter of Section 12 (Figure 3). The final part of the well number is the sequential number of the well within that particular tract.

FIGURE 3



WELL NUMBERING SYSTEM

Chapter 2. CONCLUSIONS AND RECOMMENDATIONS

Major conclusions and recommendations of this study are summarized below.

Conclusions

° In the Sonoma Valley, alluvial fan deposits form the major quantifiable ground water-yielding unit. These deposits form essentially a single aquifer. Some units in the Sonoma Volcanics contain large amounts of ground water but, because of their highly variable water-yielding characteristics, the amount of ground water in the volcanics cannot be quantified.

° Based on the computer program TRANSCAP, the total storage capacity of Sonoma Valley ground water basins is 872 000 cubic dekametres (dam^3) (708,000 acre-feet (ac-ft)). The thickness of the water-yielding materials ranges from 0 to 240 metres (m)(0 to 780 feet (ft)), with an average thickness of 80 m (260 ft). The total volume of ground water in storage as of fall 1980 was 689 000 dam^3 (559,000 ac-ft). This figure includes water of all quality types, including brackish water caused by sea water intrusion, and is based on the assumption that all ground water is unconfined.

° Based on TRANSCAP, the volume of ground water in the Sonoma Valley affected by sea water intrusion is 108 000 dam^3 (87,000 ac-ft). This reduces the volume of usable ground water in storage in the Sonoma Valley to 581 000 dam^3 (472,000 ac-ft). Intrusion affects areas south of Schellville, at or near sea level; bay mud and alluvial fan deposits have been intruded.

° Based on TRANSCAP, the volume of storage available to accept recharged surface water as of fall 1980 was 183 000 dam^3 (149,000 ac-ft). This represents 21 percent of the total storage capacity. Because of topographic constraints, ground water reservoirs in the study area rarely fill above 79 percent of storage capacity. Since the reservoirs are therefore essentially "full" and since surface water is available to meet most domestic needs, an artificial recharge program to increase the volume of ground water in storage is not needed at this time.

° Using available water level data and available data concerning the hydraulic properties of the sediments in the ground water reservoir, the average annual recharge to alluvial fan deposits is estimated to be 25 000 dam^3 (20,000 ac-ft). This recharge generally takes place in and near streambeds that have been incised into alluvial fan deposits. Recharge also takes place in the Sonoma Volcanics; direction and rate of movement of this recharged water are unknown.

° Hydrographs of wells monitored during the 1976-1977 drought indicate that more surface water could be stored underground if more storage space were made available by increased ground water use in certain areas. At present, much water runs off the land surface as rejected recharge.

° Ground water quality in alluvial fan deposits is generally good in the Bennett Mountain area. In the Sonoma Valley basin, hardness, salinity and other quality problems increase in fan deposits to the south. Available data

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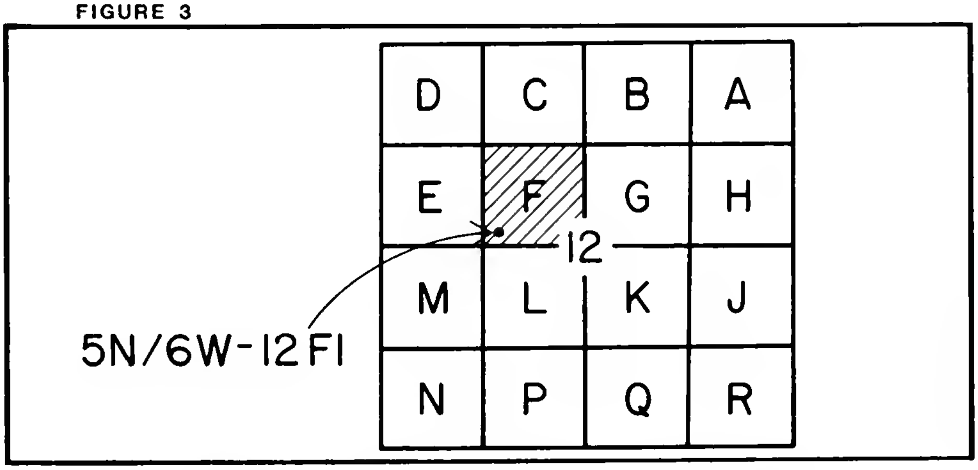

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° Ground water quality in alluvial fan deposits is generally good in the Bennett Mountain area. In the Sonoma Valley basin, hardness, salinity and other quality problems increase in fan deposits to the south. Available data

indicate that ground water from Sonoma Volcanics in the Bennett Mountain area is of good quality. In the Sonoma Valley, the Sonoma Volcanics frequently contain highly mineralized thermal ground water.

Recommendations

- A program of stream gaging and permeameter testing of soils should be implemented to more accurately determine the recharge rate of the Sonoma Valley. Ground water level monitoring should be continued to improve estimates of total ground water in storage and available storage capacity, and to detect changes in patterns of ground water use.

- When the study area has been sufficiently dewatered to make an artificial recharge program feasible, the site(s) selected should be in an area of favorable slope and soil permeability. When artificial recharge sites are selected, 24-hour constant-rate pump tests should be conducted on site to determine aquifer transmissivity. On-site drilling is necessary to determine detailed local subsurface geology.

- A program of ground water quality sampling should be implemented near Schellville to monitor inland movement of sea water. If sea water is moving inland mitigating measures that could be implemented include: (1) further reduction in ground water pumpage near the intruded area; and (2) artificial recharge of ground water via injection wells near the intruded area, since geologic conditions make percolation ponds impractical.

- A program of ground water quality sampling should be implemented in the vicinity of well 5N/5W-18D2, near the City of Sonoma, which in the past contained nitrate in excess of recommended limits. The sampling will help determine source and magnitude of the nitrate problem.

- Ground water pumpage can probably be increased with few adverse effects in areas other than the southern Sonoma Valley. If pumping is increased in the northern Sonoma Valley, such as near Boyes Hot Springs, ground water quality should be carefully monitored for lateral migration of thermal connate water from the Sonoma Volcanics. In the southern Sonoma Valley, care should be taken to avoid increased pumpage near tidal portions of Sonoma Creek, where surface water quality is poor, or near areas of known sea water intrusion. Ground water elevations in the study area should be measured biannually and examined periodically for large declines in the ground water table.

Chapter 3. OVERVIEW OF GROUND WATER GEOLOGY, HYDROLOGY, AND SOILS

This chapter presents a brief overview of the ground water geology, hydrology, and soils of the Sonoma Valley. A detailed description of these subjects has been published in DWR Bulletin 118-4, Volume 1 (Ford, 1975).

Geology and Hydrology

Geologic formations in the Sonoma Valley can be divided into water-yielding formations, nonwater-yielding formations, and formations with highly variable water-yielding properties (Figure 4). Water-yielding formations are alluvium and alluvial fan deposits. Water-yielding formations that generally produce only low yields of ground water are: bay mud deposits, the Glen Ellen and Huichica Formations, and the Petaluma Formation. Yields from the Petaluma Formation are higher when a well intercepts a lens of gravel. The only nonwater-yielding formation in the study area is the Franciscan complex. The Sonoma Volcanics has highly variable water-yielding properties; because of this variability, yields and the volume of ground water in storage cannot be quantified.

Geologic characteristics of these units and their specific yields are summarized in Table 1. The areal distribution of these units is shown on Plate 1. The subsurface distribution of these units has been determined along the cross-section lines indicated on Plate 1 and Figure 5A as A-A', B-B', C-C', and D-D'. Profiles of the four cross sections are shown on Figures 5B-E. The following paragraphs briefly describe the geologic units, beginning with the oldest rocks.

In the following geologic descriptions, well yields have been described as limited or low, moderate, and high yields. "Limited" or "low" yield means yields generally range from 5 to 380 litres per minute (L/min)(1 to 100 gallons per minute (gal/min)). With such yields, dry holes are common. "Moderate" yields generally range from 380 to 1 100 L/min (100 to 300 gal/min). "High" yields generally exceed 1 100 L/min (300 gal/min). The yield of a well is directly related to the specific yield of the formation it penetrates. For more information on well yields, see Ford (1975).

Franciscan Complex

The Franciscan complex is the oldest geologic unit in the study area (Jurassic and Cretaceous age -- see Figure 6). It is exposed along the northeastern and southwestern edges of the study area (see Plate 1). The complex includes highly variable amounts of shale, sandstone, chert, greenstone, and serpentinite. The Franciscan complex generally contains only limited quantities of water in fractures. Normally, consolidated rocks containing water only in fractures are not considered to have a specific yield. However, for this report, the Franciscan complex has been assigned a very low apparent specific yield of less than 3 percent. Because of the very low specific yield, areas composed of the Franciscan complex were not included in calculations of storage capacity in Chapter 4.

Neroly Formation

Isolated exposures of marine sediments near the eastern boundary of the study area have been assigned to the Neroly Formation of Tertiary age by Weaver (1949). The marine sediments are composed principally of medium grained tan sandstone containing casts of marine

pelecypods (Ford, 1975). No ground water quality or well yield data are available for this formation, but yields are assumed to be low because of the degree of consolidation of the sandstone. It has been assigned a low specific yield of from 3 to 7 percent.

Petaluma Formation

The Petaluma Formation, mid-to-late Pliocene in age, is exposed on the lower slopes of the hills that bound the Sonoma Valley on the west. The Petaluma Formation consists of folded continental and shallow marine to brackish-water deposits of clay, shale, and sandstone, with lesser amounts of conglomerate and nodular limestone. Occasional thick beds of diatomite are present. Abundant clay characterizes this unit; Weaver (1949) measured a 323-m (1,059-ft) thick stratigraphic section near Lakeville in the Petaluma Valley that contained 70 percent clay, shale, and clayey or shaley beds. Hydrogen sulfide has been found in wells penetrating the Petaluma Formation in the Santa Rosa Plain. The Petaluma Formation can yield moderate amounts of water when a well penetrates an appreciable thickness of sand and gravel. However, because of the large amounts of clay that characterize the unit, it has been assigned a low overall specific yield of from 3 to 7 percent.

Sonoma Volcanics

The Sonoma Volcanics, of Pliocene age, underlies the mountains surrounding the Sonoma Valley. Generally, the Sonoma Volcanics consists of a thick sequence of lava flows (labeled Tsv on Plate 1) with minor intrusive igneous rocks consisting of rhyolite, perlite, and rhyolite breccia. In some areas, lava flows are interlayered with tuff, welded tuff, and volcanic sedimentary deposits such as tuffaceous sand and volcanic gravel (labeled Tst on Plate 1). Large landslides have been mapped by Fox, et al (1973) in areas underlain by Sonoma Volcanics.

The Sonoma Volcanics has a highly variable specific yield. It is considered to be a good water producer where unwelded tuff, scoria, and volcanic sediments are present. In the Sonoma Valley, the lava flows and intrusive rocks contain water only in fractures and, therefore, are essentially nonwater-yielding except where the rocks have been highly fractured. Normally, consolidated rocks containing water only in fractures are not considered to have a specific yield. However, for this report, the Sonoma Volcanics has been collectively assigned a variable apparent specific yield of from 0 to 15 percent. Because of the variable water-yielding characteristics, areas composed of Sonoma Volcanics were not included in calculations of storage capacity in Chapter 4.

Glen Ellen Formation

The Glen Ellen Formation, of Pliocene (?) and Pleistocene age, is exposed along the base of the hills that border the Sonoma Valley to the west. It is composed of partially cemented gravel, sand, silt, and clay, locally containing much interbedded tuff. Obsidian pebbles are characteristic of the Glen Ellen. Because of the cementation of the gravels, the amount of clay present, and the degree of consolidation of the formation, well yields are low and many wells are dry. Its specific yield is believed to be low, ranging from 3 to 7 percent.

Included with the Glen Ellen on Plate 1 is the Huichica Formation of Pleistocene age. Kunkel and Upson (1960) mapped the Huichica on the eastern side of the Sonoma Valley. It consists of reworked volcanic sediments and has a specific yield similar to the Glen Ellen Formation.

Alluvial Fan Deposits and Alluvium

Alluvial fan deposits of Pleistocene and Holocene age blanket the northern and central Sonoma Valley, extending as far south as Schellville. In the northern

GUIDE TO GROUND WATER HYDROLOGY

The science of ground water hydrology deals with the distribution and behavior of ground water -- how much water is contained in any geologic material and how easily it can be extracted. The science of ground water geology deals with the effect of geology on the distribution and movement of ground water -- how different geologic materials and geologic structures determine the rate and paths of movement of ground water. By knowing the geology of an area, the subsurface hydraulic properties of that area can be estimated, because ground water hydrology and ground water geology are closely related.

Geologic formations can be divided into two groups: water-yielding and nonwater-yielding. Water-yielding formations, which usually consist of unconsolidated deposits of sand and gravel, readily absorb, transmit, and yield large quantities of ground water to wells. Nonwater-yielding formations, which usually consist of clay and consolidated rocks, yield only limited quantities of water to wells. Each geologic formation has specific hydraulic properties: porosity, permeability, specific yield, and transmissivity.

POROSITY AND PERMEABILITY

Porosity is the ratio of the volume of the voids between the particles in a sample to the total volume of the sample.

$$\text{Porosity} = \frac{\text{volume of voids}}{\text{total volume of sample}} (100) = \%$$

Porosity is not necessarily indicative of permeability, which indicates the ease with which ground water moves through a material. If the openings between the particles are small or are not connected, the permeability of the material is low. For example, clay contains a large number of small voids, so its porosity may be as high as 50 percent. Because of the physical and chemical nature of clay, it transmits very little water and it has a very low permeability, about 1.07×10^{-4} metres (3.5×10^{-4} feet) per day.* The porosity of sand and gravel is about 20 percent, much lower than the porosity of clay, but the voids in the sand and gravel are larger and are interconnected. Thus, most sands and gravels transmit water readily, having a permeability of about 1.07×10^{2} metres (3.5×10^{2} feet) per day.

A permeable geologic unit is called an aquifer. A relatively impermeable geologic unit is called an aquiclude or an aquitard because it retards the flow of water; both are called confining beds because they block the movement of ground water. Confining beds usually consist of clay or other fine-grained sediments. They contain ground water but have low permeability and cannot transmit extractable quantities. Granite is an example of an aquifuge because ground water cannot flow through it; granite is neither porous nor permeable. Ground water does flow through joints in the granite, but that geologic complication is a result of structural complexities not related to porosity or permeability. The porosity and permeability of formations composed of clay, sands, and gravels generally decrease through time as the formation becomes more consolidated.

SPECIFIC YIELD

Specific yield is the ratio of the volume of water that will drain due to gravity from a saturated sample of material to the total volume of the sample.

$$\text{Specific Yield} = \frac{\text{volume of water drained}}{\text{total volume of sample}} (100) = \%$$

The higher the specific yield of a geologic unit, the more water it will yield. Listed below are representative specific yield values for common geologic materials. Geologic materials having a more uniform grain size distribution will have a greater specific yield because of the greater total amount of space between particles. Consolidated rock and rocks such as basalt and granite are given specific yield values close to zero because water is contained only in fractures and not within the rock. The volume of water stored in fractured rock is highly variable, depending on the size and extent of the fractures, and cannot be easily quantified.

% Specific Yield	3	5	10	20	25
Geologic Material	Adobe Clay Shale	Cemented Gravel Cemented Sand Clay and Gravel Silt	Clay, Sand, & Gravel Fine Sand Quicksand Sand and Clay	Coarse Sand Loose Sand Medium Sand	Gravel Sand and Gravel

TRANSMISSIVITY

Transmissivity is the rate at which ground water will flow through a unit width of an aquifer, and is equal to the permeability of an aquifer multiplied by its thickness. The transmissivity of an aquifer or formation can generally be determined only from water level data collected during extended pumping of a water well. During a constant-rate pump test, abrupt changes in the slope of the curve from which transmissivity is determined indicate either the presence of a barrier, which impedes ground water movement, or the presence of a source of ground water recharge.

---

*"Metres per day" and "feet per day" are standard velocity units that indicate the amount of ground water that moves through a given cross-sectional area in one day:
a. 1 cubic metre of ground water moves through 1 square metre in 1 day. The units are: $1\ m^3 / m^2 / \text{day} = 1\ \text{m/day}$
b. 1 cubic foot of ground water moves through 1 square foot in 1 day. The units are: $1\ ft^3 / ft^2 / \text{day} = 1\ \text{ft/day}$

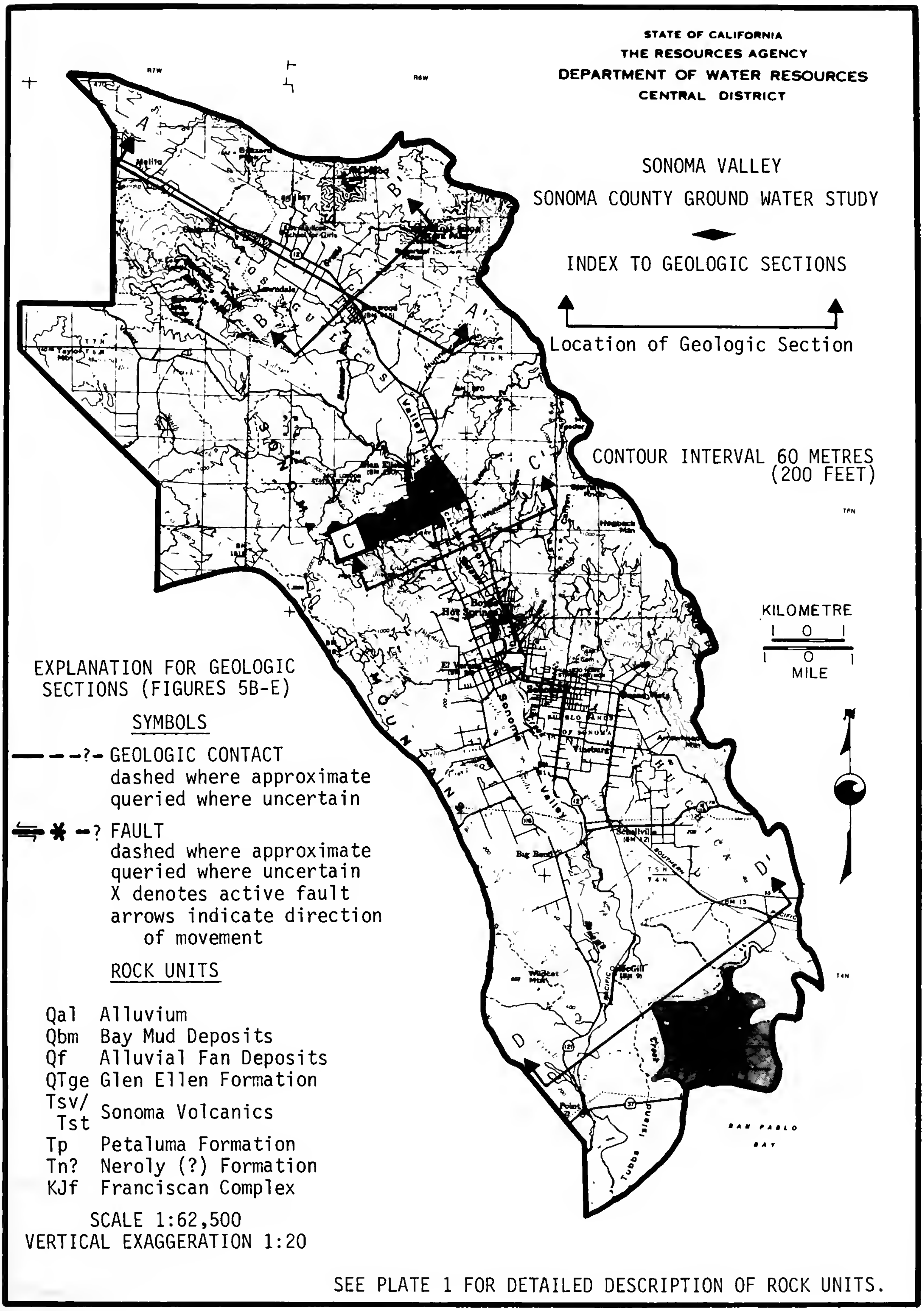
Table 1

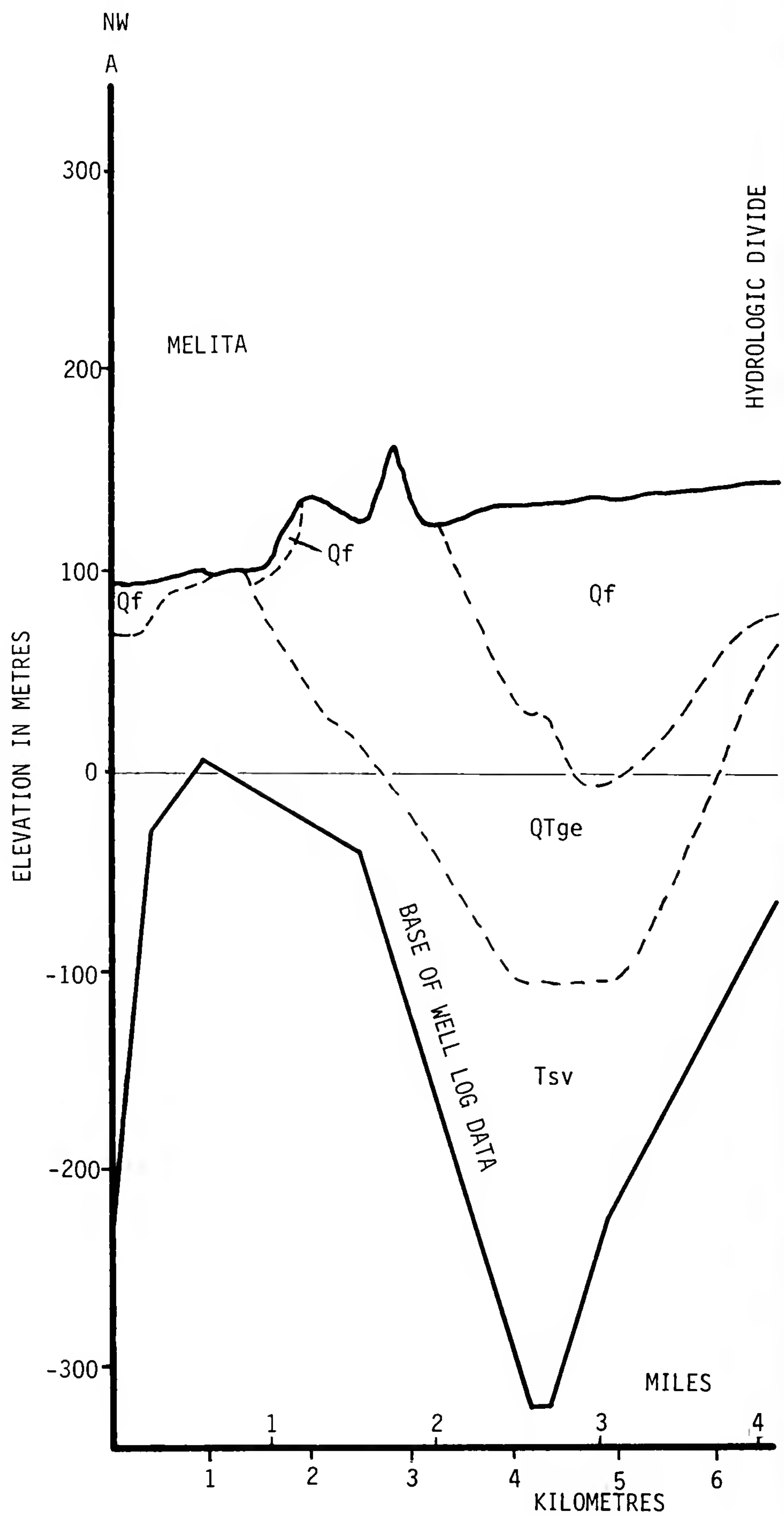
GEOLOGIC UNITS IN THE SONOMA VALLEY[1/]

Geologic Unit	Lithology[2/]	Specific Yield	Comments
Bay Mud Deposits Qbm	Mud, rich in organic matter, silty mud, silt, and fine sand.	Very low (<3%)	Low yields. Generally contain brackish water, either connate or as the result of intrusion.
Alluvium Qal	Unconsolidated sand, silt, clay, and gravel.	Variable (3-15%)	Moderate to high yields. Water quality is excellent.
Alluvial Fan Deposits Qf	Unconsolidated fine sand, silt, and silty clay, coarse sand and gravel, with gravel more abundant near fan heads.	Moderate to high (8-17%)	
Glen Ellen Formation QTge	Consolidated gravel, sand, silt, and clay; local interbedded tuff. Includes Huichica Formation named by Weaver (1949) and consisting of consolidated reworked tuff, weathered volcanic clay, silt, and similar materials.	Low (3-7%)	Yields variable, generally low. Water quality not as good as in overlying alluvium and alluvial fan deposits.
Sonoma Volcanics Tsv Tst	Volcanic flows (labeled Tsv on Plate 1) and tuff, agglomerate, and volcanic sediments (Tst).	Highly Variable (0-15%)	Variable yields, yields from Tst generally higher. Boron in some water may affect plants. Some waters thermal.
Petaluma Formation Tp	Consolidated clay and shale with minor amounts of sandstone.	Low (3-7%)	Generally low yields. Yields may be higher for wells penetrating lenses of gravel.
Neroly (?) Formation Tn(?)	Tan sandstone with casts of marine pelecypods, minor tuffaceous sandstone.	Low (3-7%)	Yields unknown, assumed to be low. Water quality unknown.
Franciscan Complex KJf	Melange, including chert, sandstone, shale, greenstone, and serpentinite.	Very low (<3%)	Low yields. Poor quality water in thermal areas, serpentinite.

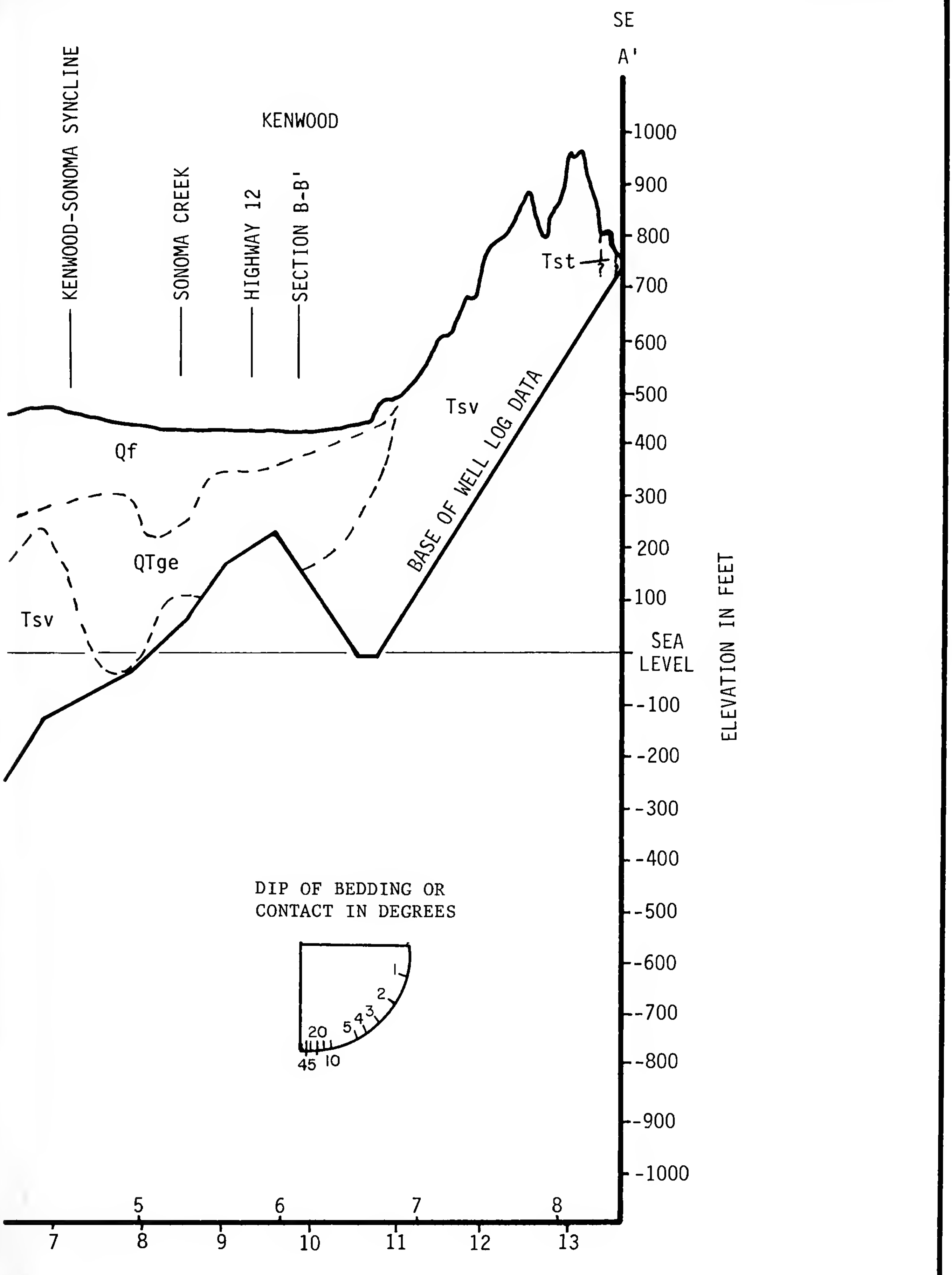
1/ After Ford (1975, Table 1).
2/ Data from Fox, et al (1973); Sims, et al (1973); Blake, et al (1974).

FIGURE 5A


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY
INDEX TO GEOLOGIC SECTIONS
Location of Geologic Section
CONTOUR INTERVAL 60 METRES (200 FEET)
KILOMETRE
1 0 1
1 0 1
MILE
EXPLANATION FOR GEOLOGIC SECTIONS (FIGURES 5B-E)
SYMBOLS
GEOLOGIC CONTACT dashed where approximate queried where uncertain
FAULT dashed where approximate queried where uncertain X denotes active fault arrows indicate direction of movement
ROCK UNITS
Qal Alluvium
Qbm Bay Mud Deposits
Qf Alluvial Fan Deposits
QTge Glen Ellen Formation
Tsv/Tst Sonoma Volcanics
Tp Petaluma Formation
Tn? Neroly (?) Formation
KJf Franciscan Complex
SCALE 1:62,500
VERTICAL EXAGGERATION 1:20
SEE PLATE 1 FOR DETAILED DESCRIPTION OF ROCK UNITS.

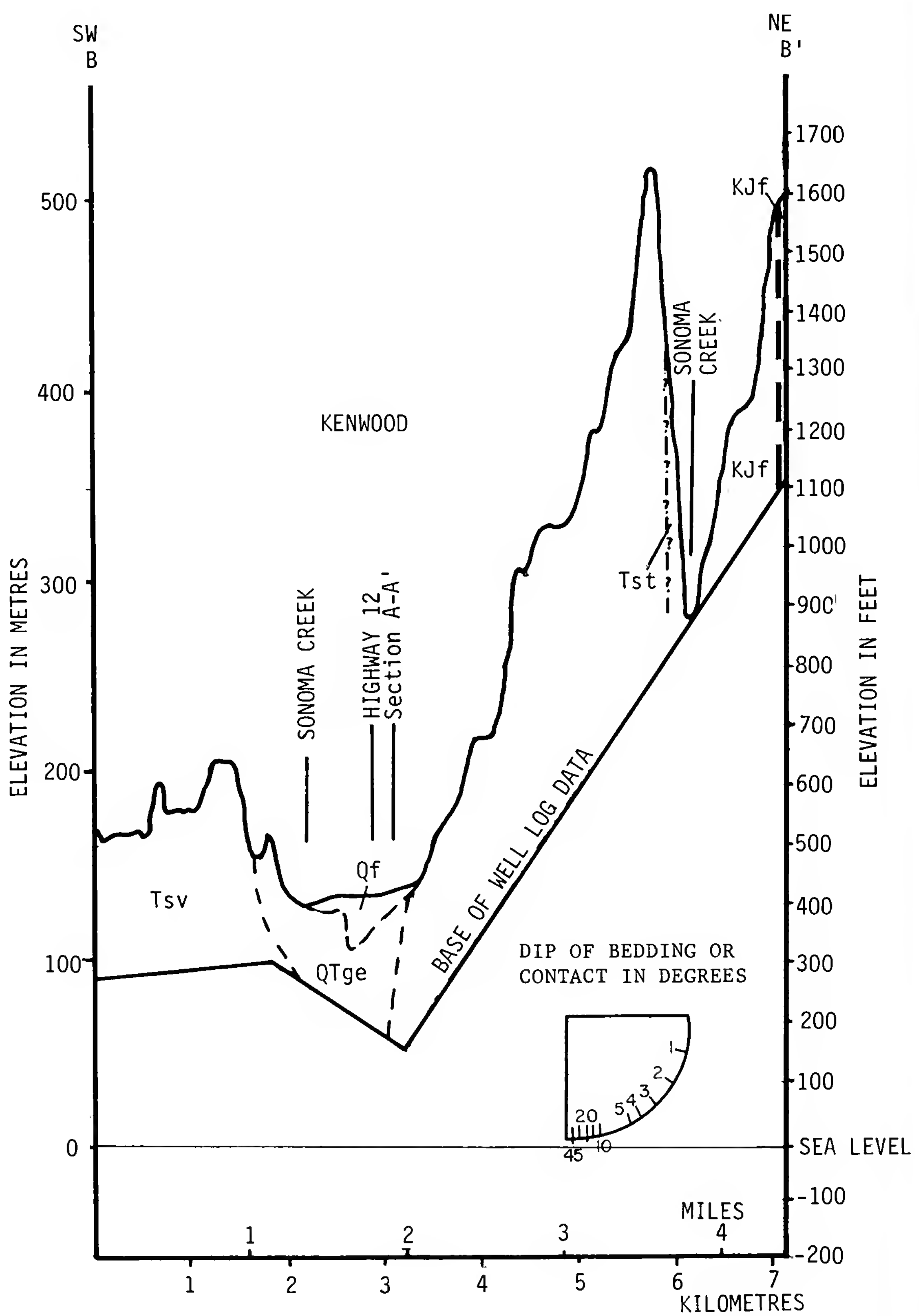


Geologic Section A-A'

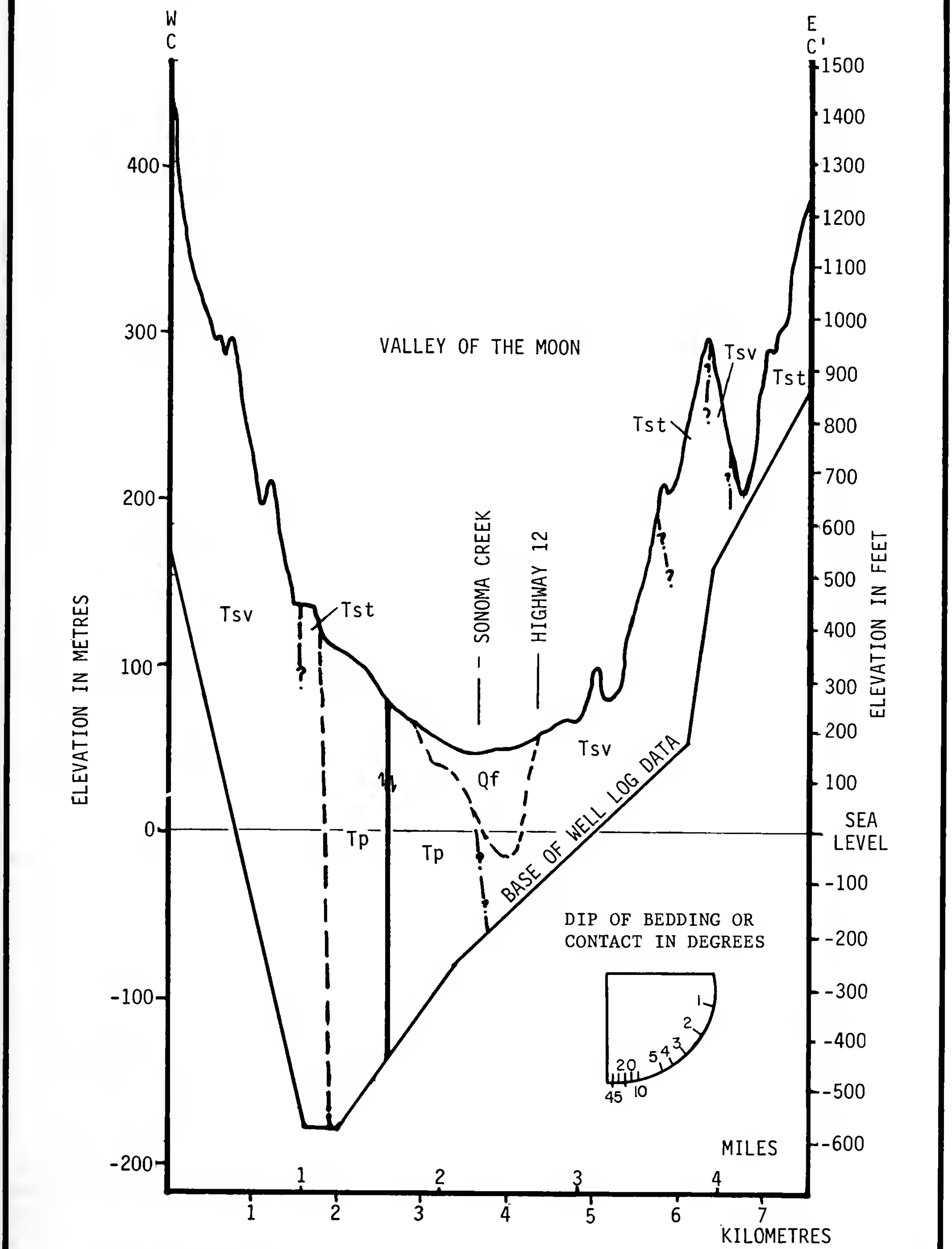


Through Melita and Kenwood

FIGURE 5C

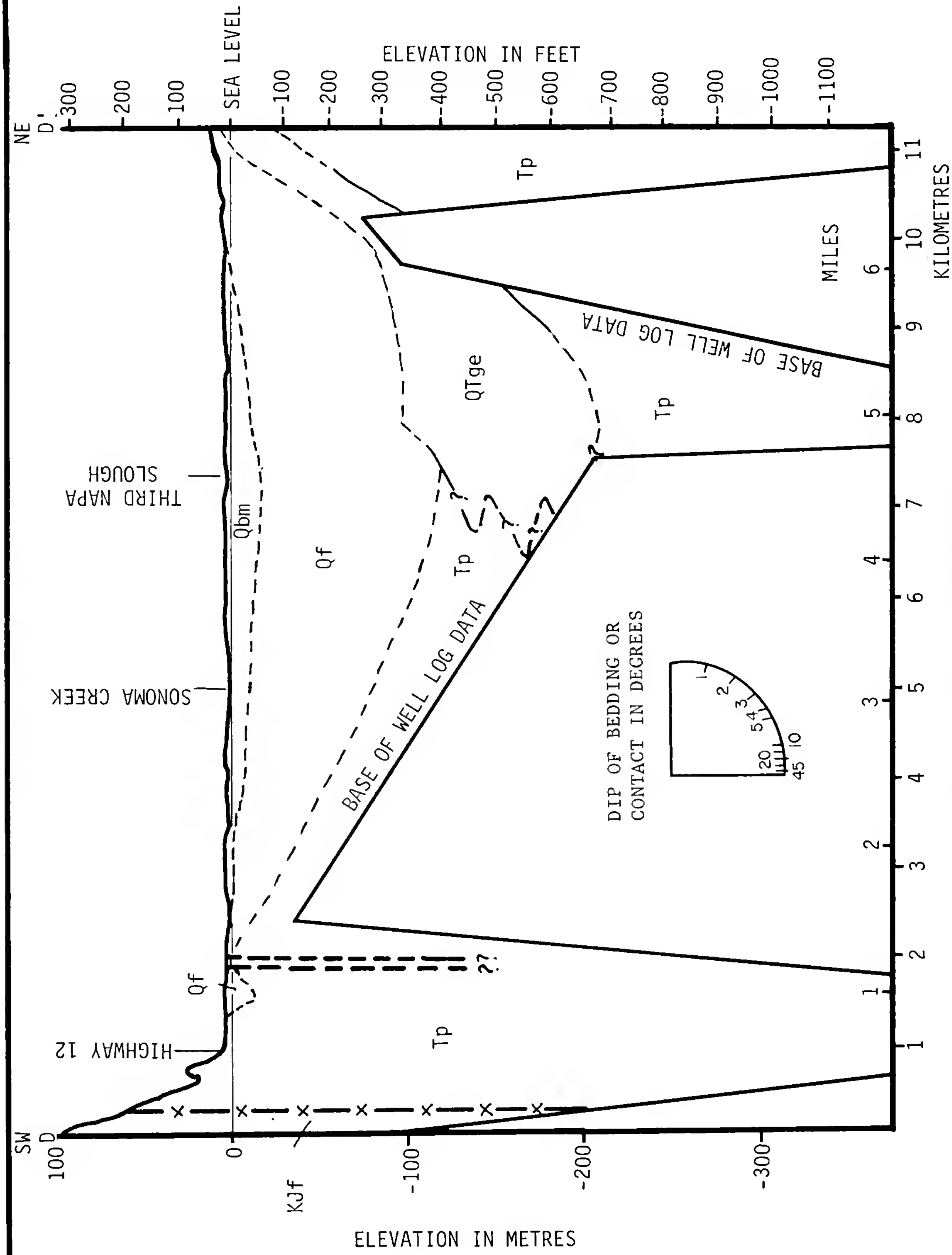


Geologic Section B-B', Through Kenwood



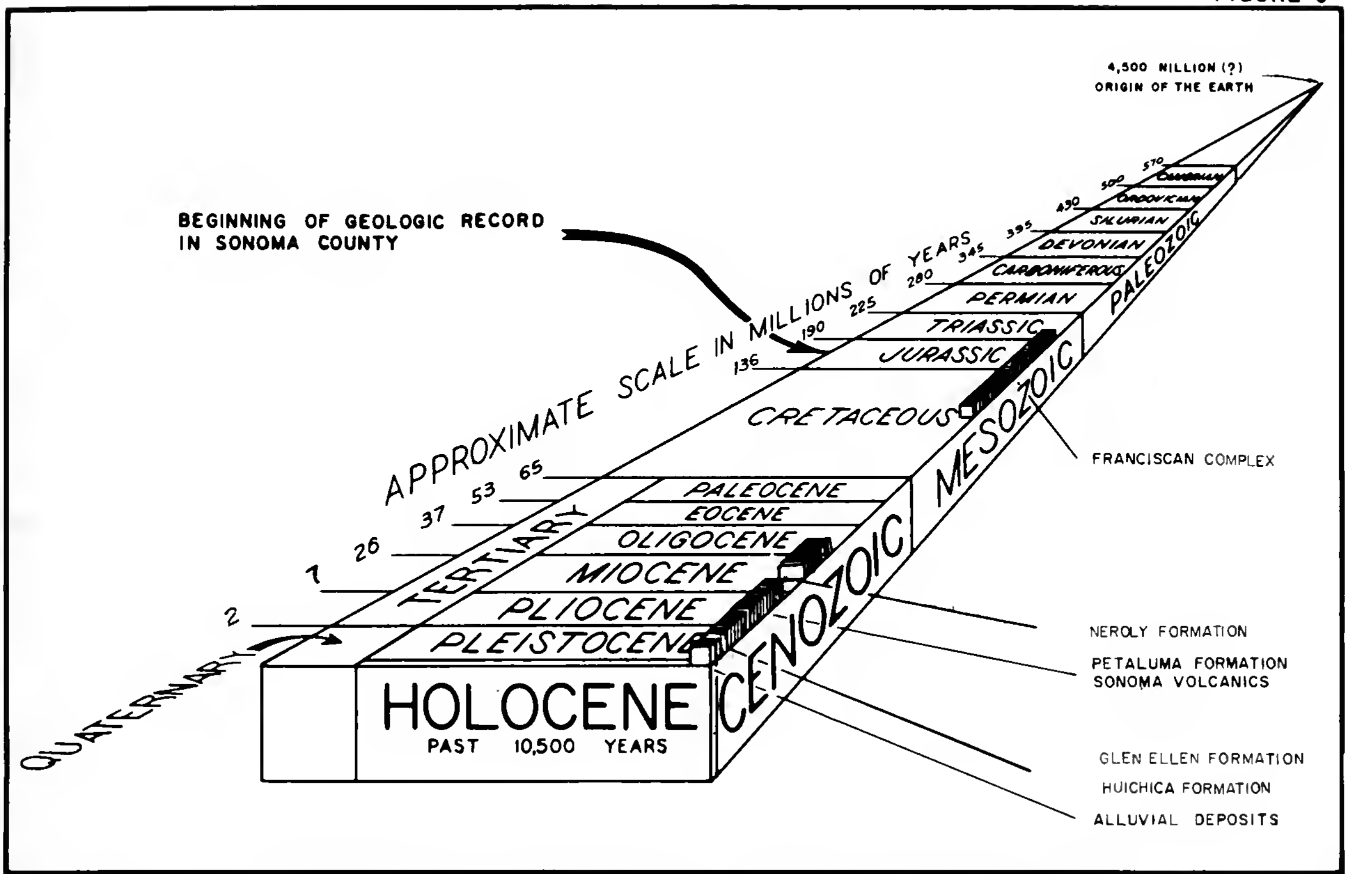
Geologic Section C-C', South of Glen Ellen

FIGURE 5E



Geologic Section D-D', South of Schellville

FIGURE 6



LOOKING BACK IN GEOLOGIC TIME—SONOMA VALLEY

part of the Sonoma Valley, the deposits consist of poorly sorted coarse sand and gravel and moderately sorted fine sand, silt, and silty clay; gravel content increases near the heads of the fans. The deposits become progressively finer-grained, containing more clay, toward the southern part of the Sonoma Valley. This change is due to a change in the rocks that were eroded and redeposited to form the alluvial fan deposits, and to the distance the eroded materials were transported before deposition.

Although problems from excessive pumping of sand have been reported for wells completed in alluvial fan deposits in the Santa Rosa Plain and Petaluma Valley, no sanding problems have been reported for similar wells in the Sonoma Valley. In the Santa Rosa Plain and Petaluma Valley, the sanding problem is caused by very fine sand from the Merced Formation, which has been eroded and redeposited within the alluvial fan deposits. The Merced Formation does not crop out in the Sonoma Valley; the major sources of the alluvial fan deposits are the Petaluma Formation and the Sonoma Volcanics, which contain little or no fine sand. Because of the unconsolidated, coarse-grained nature of much of the alluvial fan deposits, they have been given a moderate to high specific yield of 8 to 17 percent.

Isolated deposits of alluvium of Pleistocene to Holocene age dot the Sonoma Mountains on the western side of the Sonoma Valley. The alluvium is composed of interbedded sand, silt, clay and gravel. The specific yield of these deposits is variable, depending on the amount of clay present and the thickness of the deposit. Most are less than 30 m (100 ft) thick, and specific yields range from 3 to 15 percent.

Bay Mud Deposits

Bay mud deposits of Holocene age cover the southern Sonoma Valley. They are bay and marsh deposits, generally composed of mud, silty mud, silt, and small amounts of sand, and are rich in organic material. They have been covered in many areas by artificial fill. The bay mud was deposited during a higher stand of sea level, and much sea water was trapped in the sediments as they were deposited; bay mud is still being deposited on the floor of San Pablo Bay. Since little fresh water has moved through the bay muds since they were deposited, water pumped from them is generally brackish to highly saline. The bay muds have a low permeability and a very low specific yield of less than 3 percent.

Folds and Faults

Ground water reservoirs can be modified by folds and faults. Folds are upward and downward warps in geologic formations caused by regional geologic forces. Upward warps, called anticlines, can influence ground water by inducing flow away from the centerline or axis of the fold; downward warps, called synclines, can cause ground water to flow toward the fold axis. Folds are generally located by measuring the slope of beds of sand, clay, and gravel. When these beds are not well exposed, folds can be difficult to locate and verify.

There are many small folds within the Petaluma Formation, Sonoma Volcanics, and Glen Ellen Formation. These folds occur mostly in the mountains that surround the Sonoma Valley; they do not directly affect the alluvial fan deposits, which contain most of the ground water in the Sonoma Valley.

The only fold that has been mapped across the valley floor is the Kenwood-Sonoma Syncline (Cardwell, 1958), a large feature that may have been partly responsible for the creation of the original Sonoma Valley. The syncline extends from Kenwood northwest along the long axis of the valley. Alluvial fan deposits along the axis of the syncline formed after the deformation took place and are not folded. Because of folding of the Glen Ellen Formation, ground water in the Glen Ellen moves toward the axis of the syncline (see Plate 1).

Faults are fractures in the rock along which the rocks on either side have been moved. The fracture may or may not intersect the earth's surface. Faults sometimes create zones of crushed and broken rock along the fault plane. This crushed material, known as gouge, consists of clay-sized particles and can impede the movement of ground water across the fault, thus acting as a ground water barrier. Faults can also affect ground water movement by thinning water-yielding sands and gravels on the upthrown side of the fault; higher topographic relief increases the rate of erosion. Water-yielding materials may be thicker on the downthrown side if sediments are being deposited during a period of continued downward movement of one side of the fault.

Although there are many faults in the mountains surrounding the Sonoma Valley, no faults have been mapped in the alluvial fan deposits, which contain most of the ground water. Faults near Rodgers Creek and Glen Ellen cut through the Petaluma and Glen Ellen Formations. Many of these faults have been extended by investigators into the fan deposits as concealed faults. Although not apparent on the surface, some of these faults may

cut fan deposits below the land surface. Faults in the mountains may impede the flow of ground water that moves downslope to recharge the alluvial fan deposits, but many of the rocks in the mountainous areas are essentially nonwater-yielding. Faults in brittle volcanic flows of the Sonoma Volcanics have shattered the rocks to form zones of high permeability.

Soils

Soil is a product of many factors:

- The geologic formation that underlies it and from which it formed.
- The slope of the land.
- Age of the soil.
- Climate, especially the amount of rainfall.
- Organisms, especially native vegetation.

Of these factors, geology is most important. For example, coarser-textured soils form on the sandy alluvial fan deposits and heavy clay soils form on the fine-grained bay mud deposits. Slope generally affects the thickness of the soil profile, with thicker, older soils forming on flatter slopes. Age of the soil and the amount of rainfall control the degree to which the soil profile develops into distinct layers or "horizons". Young soils, especially in arid climates, have relatively little profile development. Organisms such as plants and bacteria modify soil characteristics such as the amount of nitrogen and organic matter in the soil.

Soil characteristics in turn control the types of crops that can be grown in an area, the amount of surface water that infiltrates to the ground water body, and the effectiveness of septic-tank leach-field sewage disposal systems. Agricultural crops grow best on deep, permeable soils. Some nearly impermeable adobe soils are suitable only for pasture. Permeable soils are necessary for recharge of surface water to the ground water body. Soils that have neither a very high infiltration rate (faster than 2 minutes per centimetre or 5 minutes per inch) nor low infiltration rate (slower than 25 minutes per centimetre or 60 minutes per inch) are necessary for leach-field siting.

In general in the Sonoma Valley, permeable soils have formed on some alluvial deposits (labeled Qf and Qal on Plate 1), on some sedimentary units in the Sonoma Volcanics (Tst), and on some portions of the Glen Ellen (QTge) and Petaluma (Tp) Formations. Poorly permeable soils have generally formed on bay mud deposits (Qbm), on some units in the Sonoma Volcanics (Tsv), and on the Franciscan complex (KJf).

In this report, areas considered to be natural or potential artificial recharge areas have a soil infiltration rate greater than 1.5 centimetres (0.6 inch) per hour and a land slope less than 15 percent. These criteria were developed by the U. S. Geological Survey during recharge studies in the Santa Cruz area (Muir and Johnson, 1979). Approximately 14 percent of the study area has been tentatively classified as recharge areas. Locations of the recharge areas are discussed in Chapter 5.

Chapter 4. GROUND WATER SUPPLY IN THE SONOMA VALLEY

Ground water supplies can be estimated once the geologic and hydrologic characteristics of a basin are understood. In the Sonoma Valley, the volume of ground water is controlled by the thickness of the water-yielding alluvial fan deposits. The potential for sea water intrusion may govern the volume of fresh ground water that should be extracted in the southern Sonoma Valley.

The study area contains 676 000 dam^3 (548,000 ac-ft) of ground water in water-yielding materials that average 80 m (260 ft) in thickness. Long term annual extractions from the basin should not exceed the average annual recharge to the basin if permanent depletion of the ground water in storage is to be avoided. Using the results of the computer program TRANSCAP and ground water level data from 1950 through 1980, the average annual recharge to the basin was estimated to be 25 000 dam^3 (20,000 ac-ft). The estimated volume of ground water pumpage in the Sonoma Valley in 1980 is 7 000 dam^3 (6,000 ac-ft) (derived from Finlayson, 1980, Table 13). If natural recharge rates could be determined more accurately, a sustained yield figure could be calculated; it would be a more accurate reflection of the ground water potential of the basin than the estimate of average annual recharge given in this report.

Method of Investigation Using TRANSCAP

In the Sonoma Valley, the TRANSCAP (transmissivity and storage capacity) computer program was used to determine:

° Total storage capacity.

° Volume of ground water in storage.

° Volume of storage available to store recharge.

° Estimated annual natural recharge.

A detailed description of the TRANSCAP computer program is given in Miyazaki (1980).

The initial step in using TRANSCAP to study a ground water basin is to divide the basin into "cells". In the Sonoma Valley, each cell is equivalent to a 260-hectare (640-acre) section, or to that portion of a section underlain by water-yielding materials. Study area and cell boundaries are shown in Figure 7. Where the surficial geology is composed mainly of the Franciscan complex, cells were not evaluated because this complex is nonwater-yielding.

Where the surficial geology is composed mainly of Sonoma Volcanics, cells, or portions of cells, were not evaluated because volcanic rocks are highly variable in their hydraulic properties.

Water well drillers' reports are collected for each cell to be evaluated. A sample well driller's report is shown in Figure 8. The right-hand column of the report lists the geologic materials encountered during drilling of the well. The materials encountered in each well are coded into the computer according to specific yield. This specific yield information is the basic data used by the TRANSCAP program.

The TRANSCAP program adjusts all wells within a cell to the average elevation of the land surface in that cell. The program then averages all specific yield data from all wells in a cell for specified depth intervals, generally 3 m

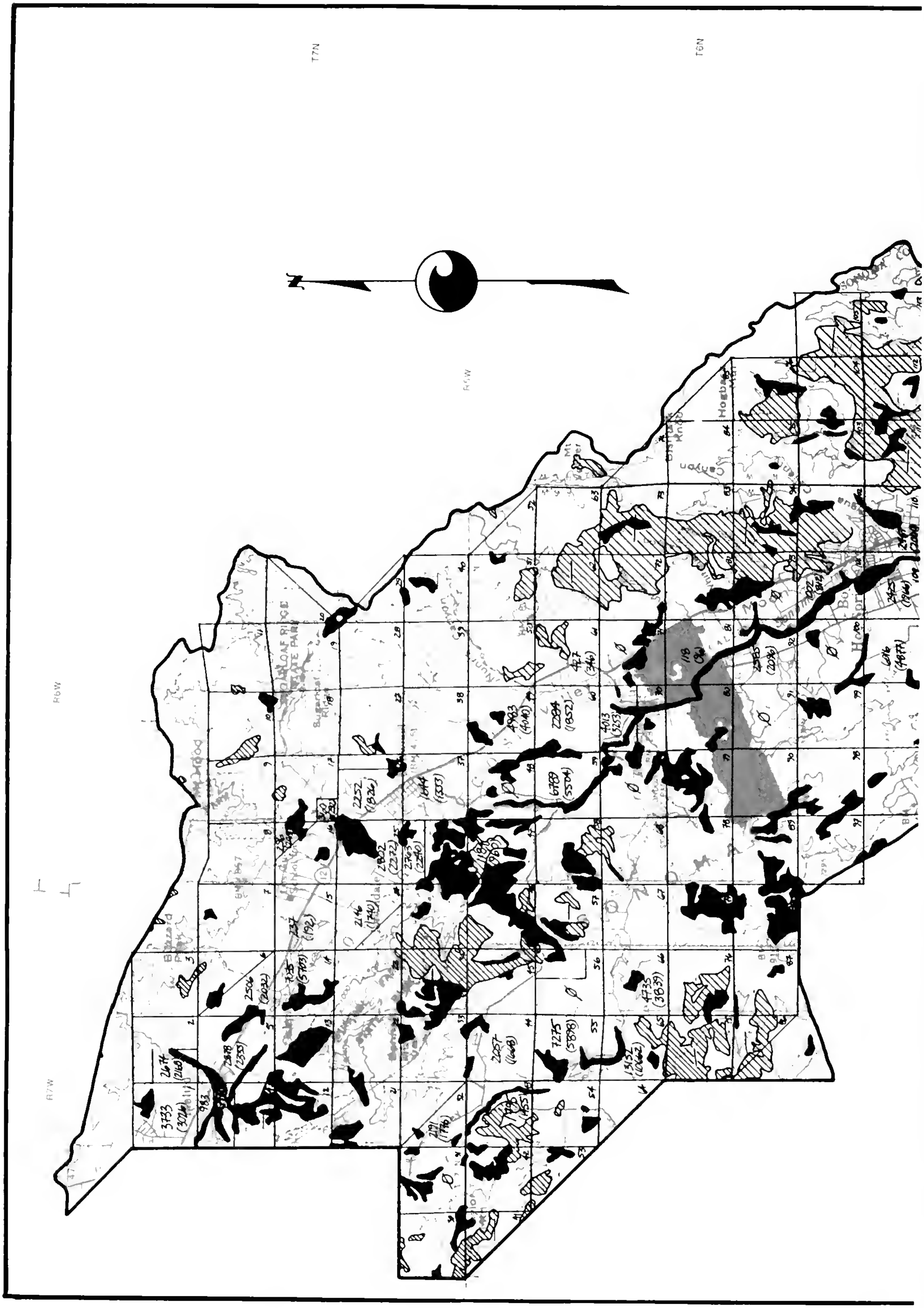
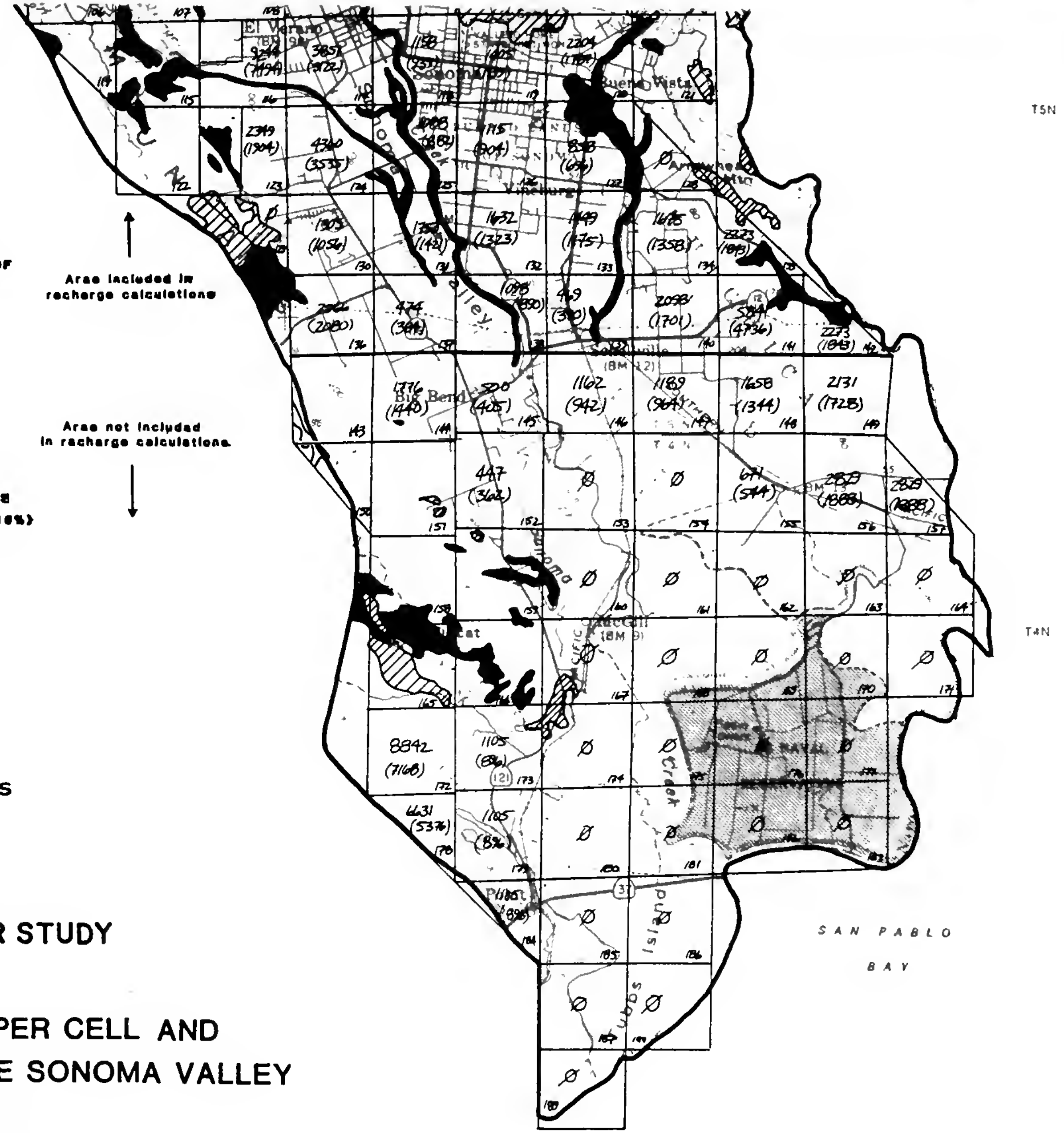


FIGURE 7



EXPLANATION

AVAILABLE STORAGE CAPACITY -FALL 1980

9207	AVAILABLE STORAGE CAPACITY IN CUBIC DEKAMETRES (ACRE-FEET)
(8633)	
57	CELL NUMBER

AVAILABLE STORAGE CAPACITY NOT CALCULATED IF AREA 1) COMPOSED OF NONWATER-YIELDING FRANCISCAN COMPLEX 2) COMPOSED OF SONOMA VOLCANICS WITH HIGHLY VARIABLE WATER-YIELDING CHARACTERISTICS

NATURAL RECHARGE AREAS

- RECHARGE AREA (SOIL INFILTRATION RATE GREATER THAN 0.6"/HR., SLOPE LESS THAN 15%)
- POTENTIAL RECHARGE AREA (IF SLOPE DOES NOT EXCEED 15%)
- SLOW RECHARGE AREA (SOIL INFILTRATION RATE LESS THAN 0.6"/HR.,OR SLOPE GREATER THAN 15%)

RECHARGE AREAS DETERMINED USING U.S. SOIL CONSERVATION SURVEY MAPS (Miller 1972), AFTER Mair and Johnson(1979)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

AVAILABLE STORAGE CAPACITY PER CELL AND AREAS OF NATURAL RECHARGE IN THE SONOMA VALLEY

SCALE

.5 0 1 2 3 4 5 KILOMETRES

.5 0 1 2 3 4 5 MILES

FIGURE 8

ORIGINAL
File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

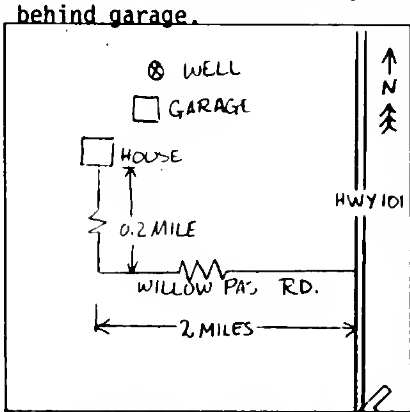
Do not fill in
No. SAMPLE

Notice of Intent No. ____
Local Permit No. or Date ____

State Well No. ____
Other Well No. ____

(1) OWNER: Name Alice Mar
Address 212 South Willow Pass Road
City Woodlake, California Zip 93563

(2) LOCATION OF WELL (See instructions):
County Sonoma Owner's Well Number 74-2
Well address if different from above ____
Township 7N Range 6W Section 19
Distance from cities, roads, railroads, fences, etc. 4 miles west of Woodlake, 2 miles east of Highway 101, 0.2 mi. north of Willow Pass Road, NE of house behind garage.



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☒
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other ☐

(5) EQUIPMENT:
Rotary ☒ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 1/8-1/4"
Diameter of bore 12"
Packed from ____ to ____ ft.

(7) CASING INSTALLED:
Steel ☒ Plastic ☐ Concrete ☐

(8) PERFORATIONS:
Type of perforation or size of screen ____

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	152	8"	1/4"	40	51	100
				129	143	

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 50 ft.
Were strata sealed against pollution? Yes ☐ No ☒ Interval ____ ft.
Method of sealing Cement Grout

(10) WATER LEVELS:
Depth of first water, if known 23 ft.
Standing level after well completion 28 ft.

(11) WELL TESTS:
Was well test made? Yes ☒ No ☐ If yes, by whom? A-OK Drilling
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test 23 ft At end of test 37 ft
Discharge 100 gal/min after 24 hours Water temperature 67°F
Chemical analysis made? Yes ☒ No ☐ If yes, by whom? Dow Lab
Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth ____ ft. Depth of completed well ____ ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	4	top soil
4	23	brown sandy loam
23	40	brown clay and gravel
40	41	coarse sand and pebble gravel
51	68	brown sandy with minor clay
68	92	blue sand
92	97	coarse sand with shell fragments
97	103	sand and pebble gravel with minor clay
103	125	red volcanic rock
125	129	black crystal vitric tuff
129	143	andesite
143	147	dark grey volcanic ash
147	152	scoria and volcanic ash
152	165	fractured andesite

Work started 16 June 1959 Completed 21 June 1959

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Signed Seymour Rocks
(Well Driller)
NAME A-OK Drilling Co.
(Person, firm, or corporation) (Typed or printed)
Address 2664 So. Bascomb
City Woodlake, CA Zip 93563
License No. 000001 Date of this report 20 July 1959

DWR 188 (REV. 7-76)

SAMPLE WATER WELL DRILLERS REPORT

(10 ft). The averaged specific yield data are converted to transmissivities using equations of a curve developed by the DWR investigation of the Livermore and Sunol Valleys (Ford and Hills, 1974). For specific yield values from 3 to 9, the curve is described by the equation:

$$\Delta T = \Delta D \cdot 10^{\left[3.5319 - \frac{7.16288}{|SY| - 0.84}\right]}$$

and for specific yield values greater than 9, the curve is described by the equation:

$$\Delta T = \Delta D \cdot (100\,|SY| - 500)$$

where ΔT = incremental transmissivity,
ΔD = incremental depth, and
$|SY|$ = absolute value for average specific yield for a given interval.

When no drillers' logs were available for a cell, transmissivity and storage capacity values from another cell with similar geology were used.

A sample TRANSCAP printout in customary units is shown in Figure 9. The variables listed in the upper left-hand corner of the table describe the values used to set up TRANSCAP for this cell. Increment of Depth = 10 indicates that specific yields were averaged over 10-ft (3-m) intervals.

Node Elevation Control is the average elevation of the land surface within the cell. Node Surface Area is the surface area, in acres, of the cell. Note that the center point in a cell is called the "node".

The figure describes hydrologic properties by intervals: either as "Depth" below land surface, or "Elevation" relative to sea level. For example, for the interval from 10 to 20 ft (3 to 6 m) above sea level or 80 to 90 ft (24 to 27 m) below land surface, the "average specific yield" is 10.30 percent, the "unit width transmissivity" is 5,300 gallons/day (20 000 litres/day) and the "storage capacity" is 673 ac-ft (830 dam^3). These computer-generated numbers are rounded to one or two significant figures before use, to avoid giving an erroneous impression of precision.

To determine the storage capacity of any cell, the bottom of the water-yielding zone must first be determined. The graph in Figure 9 entitled "unit width summation of transmissivity plot" shows a profile of the transmissivity in the sample cell. Points on the graph represent unit width transmissivity values that have been summed starting at the lowest elevation evaluated for the cell. Summed unit width transmissivity values are listed in the right-hand column labeled "TR VALUE" opposite from the corresponding elevation. The numbers across the top of the graph are summed unit width transmissivities in thousands of gallons per day.

The point at the lowest elevation on the graph represents 0. As elevation increases, the points on the graph move from left to right, and the heading is read from left to right, lowest line first (0 to 500). When the summed transmissivities exceed 500 thousand gallons per day, the graph doubles back, and the headings are read from right to left (500 to 1,000). When the summed transmissivities exceed 1,000 thousand gallons per day, the graph again doubles back and the headings are read from left to right (1,000 to 1,500). The more horizontal the line on the graph, the more permeable the water-yielding zone. The more vertical the line, the more that zone functions as a confining bed. The bottom of the water-yielding zone is determined from the TRANSCAP graph and is verified by comparison with geologic maps and cross sections. The top of the water-yielding zone is generally assumed to be the land surface. The net storage capacity of the water-yielding zone is calculated by subtracting the "storage capacity to bottom" figure at the bottom of the water-yielding zone from the corresponding figure at the top of the water-yielding zone.

FIGURE 9

SONOMA COUNTY
GROUND WATER INVESTIGATION
DEPTH INCREMENT CALCULATIONS FROM SPECIFIC YIELD

NODE 7

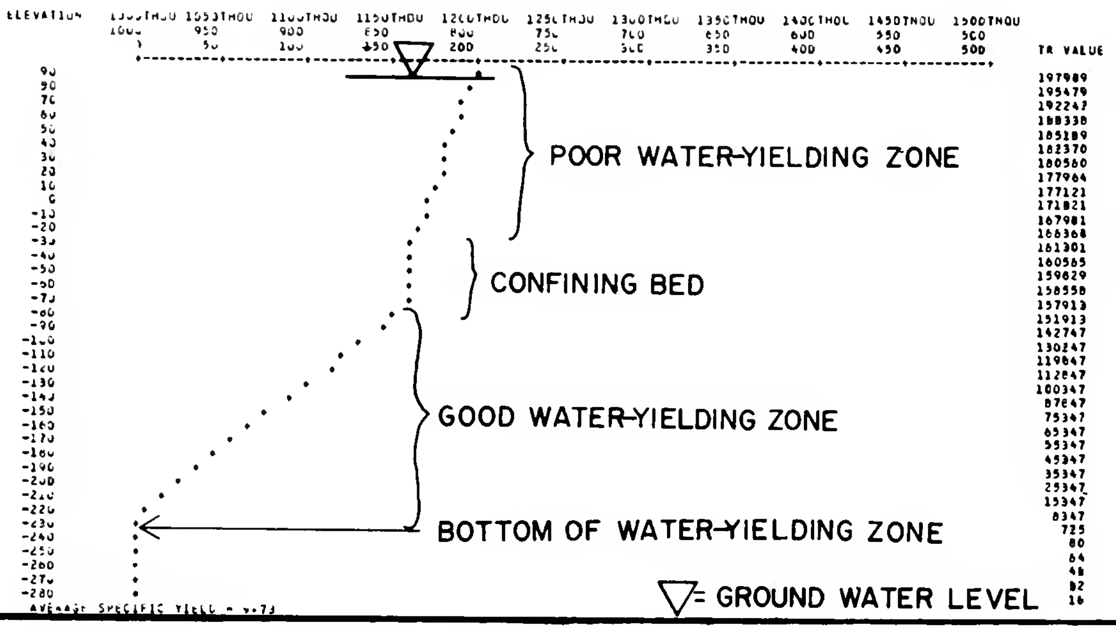
PAGE 1
DATE 10/27/81

INCREMENT OF DEPTH = 10
NODE ELEVATION CONTROL = 100
NODE SURFACE AREA (ACRES) = 654

SY VALUE FOR CLAY = 3

DEPTH	ELEVATION	AVERAGE SPECIFIC YIELD (IN PERCENT)	UNIT WIDTH TRANSMISSIVITY (GAL/DAY)	UNIT WIDTH TR FOR USE IN MODEL AC-FT/YR	STORAGE CAPACITY (ACRE-FEET)	STORAGE CAPACITY TO BOTTOM (ACRE-FEET)	NO. OF SAMPLES
10	90	7.17	2510	221	468	24178	12
20	80	7.85	3232	219	513	23710	13
30	70	8.46	3409	215	553	23197	13
40	60	7.77	3149	211	508	22644	13
50	50	7.46	2819	207	487	22136	13
60	40	6.46	1810	204	422	21649	13
70	30	7.25	2596	202	474	21227	12
80	20	5.30	843	199	346	20753	10
90	$\boxed{10}$	$\boxed{10.30}$	$\boxed{5330}$	198	$\boxed{673}$	20407	10
100	0	8.40	3540	192	549	19734	10
110	-10	6.25	1613	188	408	19185	8
120	-20	9.50	5067	186	621	18777	8
130	-30	5.14	736	180	336	18156	7
140	-40	5.14	736	179	336	17820	7
150	-50	5.86	1271	179	383	17484	7
160	-60	5.00	645	177	327	17101	6
170	-70	11.00	6600	177	719	16774	6
180	-80	14.17	9166	170	926	16055	6
190	-90	17.50	12500	160	1144	15129	6
200	-100	15.40	10400	146	1007	13985	5
210	-110	12.00	7000	134	784	12978	4
220	-120	17.50	12500	126	1144	12194	2
230	-130	17.50	12500	112	1144	11050	2
240	-140	17.50	12500	96	1144	9906	2
250	-150	15.00	10000	84	981	8762	1
260	-160	15.00	10000	73	981	7781	1
270	-170	15.00	10000	62	981	6800	1
280	-180	15.00	10000	50	981	5819	1
290	-190	15.00	10000	39	981	4838	1
300	-200	15.00	10000	28	981	3857	1
310	-210	14.00	9000	17	915	2876	1
320	-220	10.00	5822	7	654	1961	1
330	-230	5.00	645	0	327	1307	1
340	-240	3.00	16	0	196	980	1
350	-250	3.00	16	0	196	784	1
360	-260	3.00	16	0	196	588	1
370	-270	3.00	16	0	196	392	1
380	-280	3.00	16	0	196	196	1

UNIT WIDTH SUMMATION OF TRANSMISSIVITY PLOT



SAMPLE TRANSCAP PRINTOUT

The program TRANSCAP calculates storage capacities to the bottom of the deepest well in each cell. No storage capacity information is available for that portion of an aquifer below the bottom of the deepest well. For cells where the aquifer extends below the well data, the storage capacity from TRANSCAP is a minimum value; the true storage capacity would be higher.

In the Sonoma Valley, the thickness of the water-yielding materials ranges from 0 to 240 m (0 to 780 ft), with an average thickness of 80 m (260 ft). Some of the thickest sections are near the City of Sonoma.

To determine the volume of water in storage, the average ground water level for the cell is determined from a ground water level map. The volume of water in storage is determined by subtracting the "storage capacity to bottom" figure at the bottom of the water-yielding zone from the corresponding figure at the ground water table elevation. This method assumes that all ground water in the cell is unconfined. If, however, ground water is confined, the volume of ground water in storage estimated by this method will be too large. The more confined the ground water, the larger the error will be.

Water level information for fall 1980 (Figure 10) was combined with the product of TRANSCAP to determine the storage capacity, the total volume of water in storage, the available ground water storage capacity, and the amount of fresh water displaced by sea water in the Sonoma Valley. Available storage capacity indicates the capability of the cell to store additional ground water from natural or artificial recharge. Available storage capacity (estimated for cells where no drillers' logs were available) is given in Figure 7. The volume of ground water in storage per cell is given in Figure 11.

Total Water in Storage

The total volume of water in storage and the available ground water storage capacity are given in Table 2. There were not enough ground water level data available before fall 1980 to construct ground water level maps, but hydrographs of wells that have been monitored in the past were examined for trends.

Ground water levels in the Sonoma Valley have generally remained constant over the period of record. One shallow well in the vicinity of the City of Sonoma did recover 4.5 m (15 ft) to its historic normal level after surface water deliveries from the SCWA began in 1965. Ground water levels have remained relatively steady since that time except during the drought of 1976-1977.

Ground water levels in monitored wells in the Sonoma Valley normally drop 3 m (10 ft) between the spring water level (highest of the year) and the fall water level (lowest of the year). During the 1976-1977 drought, ground water levels dropped an average of 2 m (7 ft) below the normal fall low, but in most areas, water levels had returned to normal by spring 1978. In general, therefore, the hydrographs indicate that the volume of ground water stored in the Sonoma Valley has not changed much over time.

Volume of Ground Water Affected by Sea Water Intrusion

Sea water intrusion generally affects the southern Sonoma Valley south of Highway 121. The bay mud deposits in this southern part of the valley (Plate 1) generally contain brackish water that was trapped between the clay particles when the material was deposited. Some alluvial fan deposits in the same area produce brackish water as a result of inland movement of sea water in response to ground water pumping.

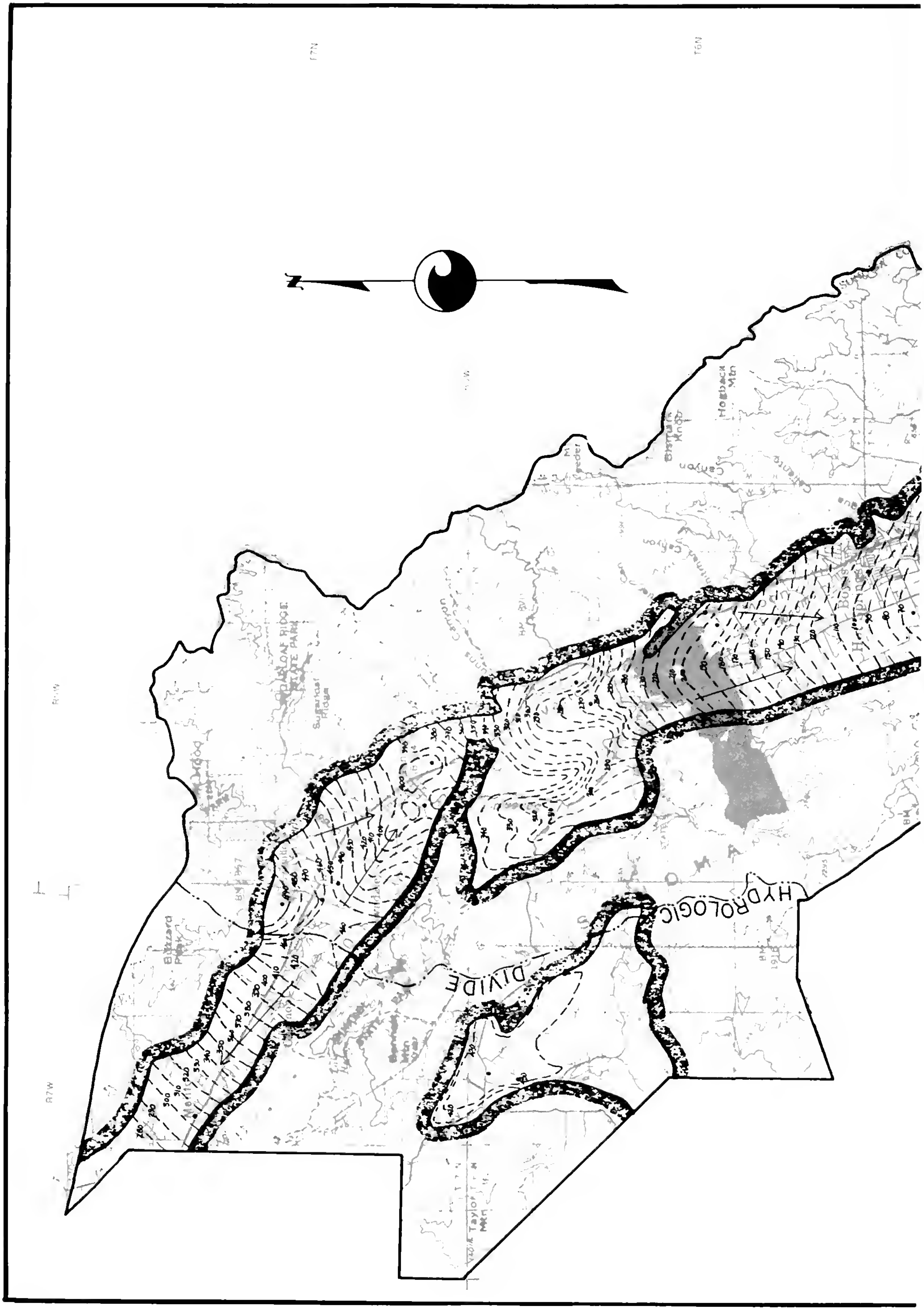
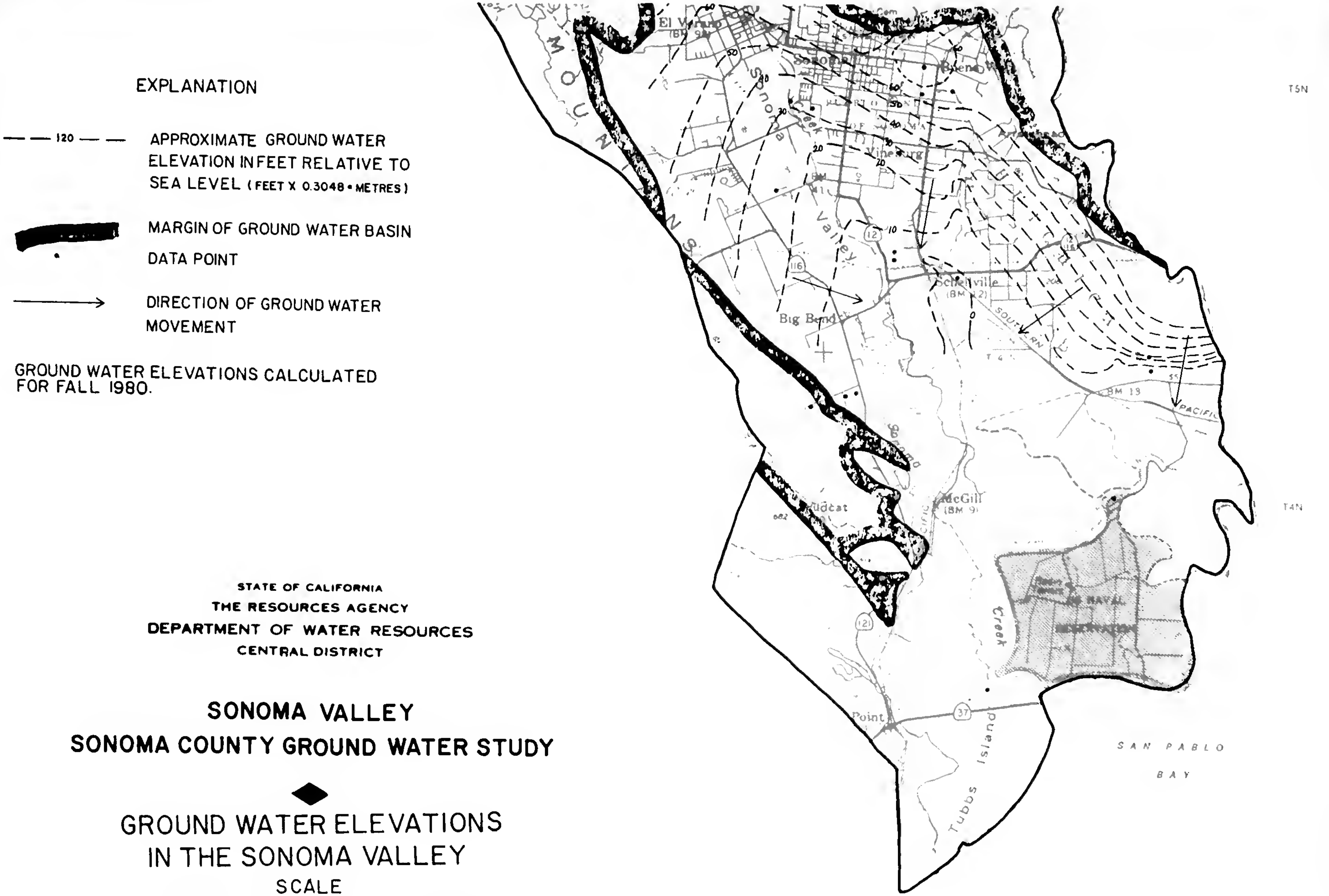

HYDROLOGIC
DIVIDE

FIGURE 10



STATE OF CALIFORNIA
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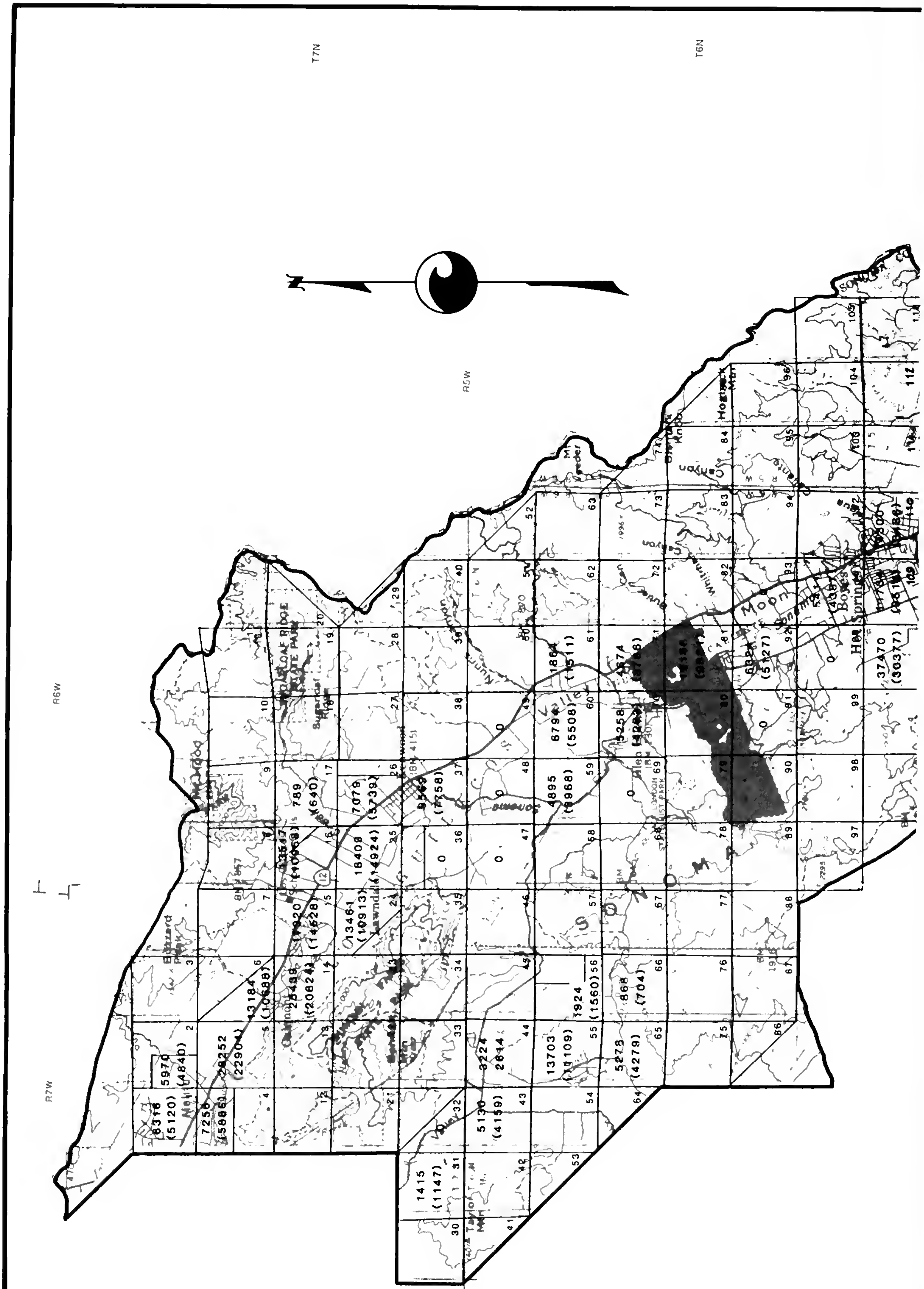
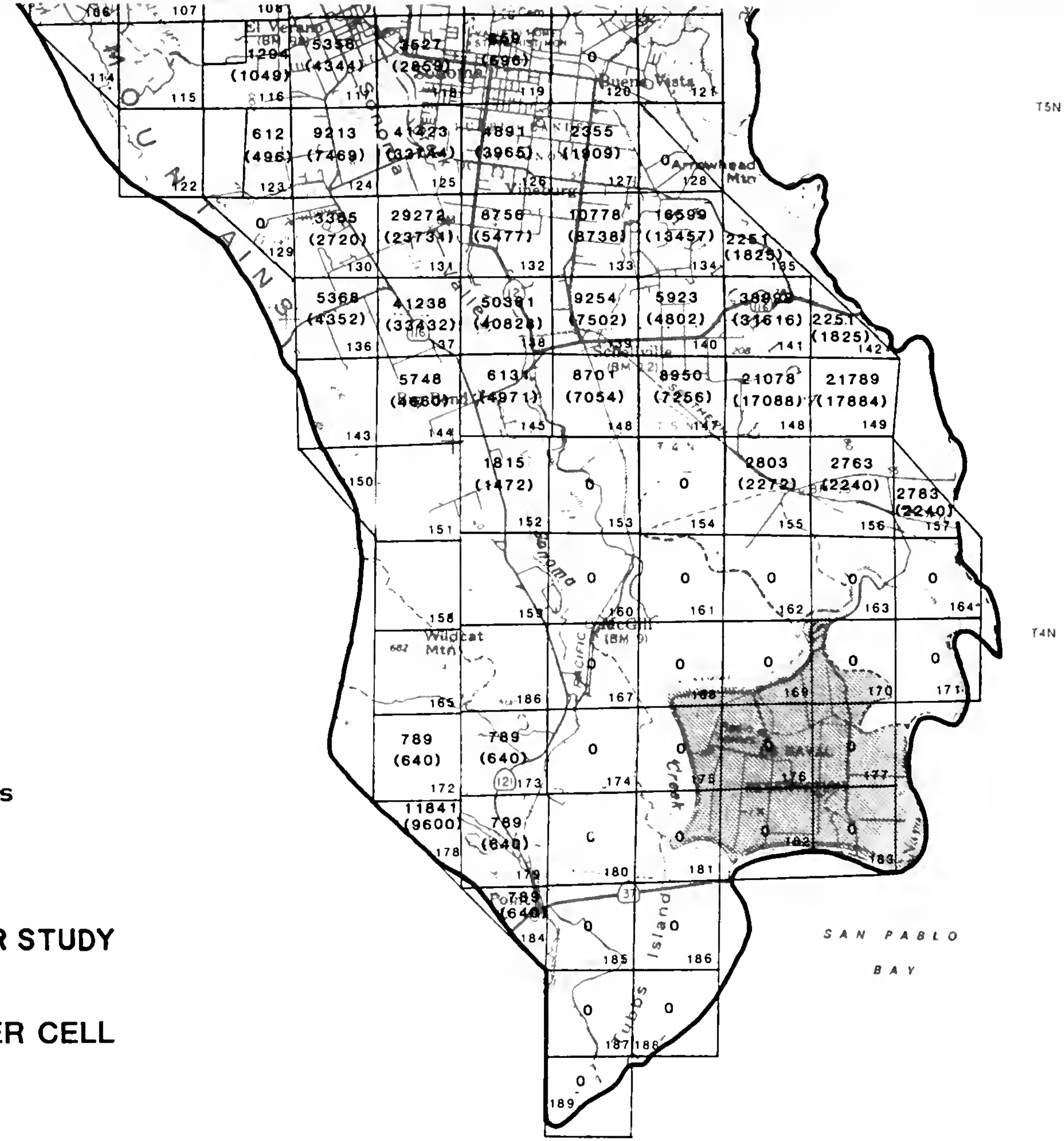
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

GROUND WATER ELEVATIONS IN THE SONOMA VALLEY

SCALE
1 .5 0 1 2 3 4 5 KILOMETRES
1 .5 0 1 2 3 4 5 MILES


T7N
T6N
R7W
R6W
R5W
Hot Springs
Boyes



EXPLANATION

GROUND WATER IN STORAGE -FALL 1980

23589 (20104) — GROUND WATER IN STORAGE IN CUBIC DEKAMETRES (ACRE-FEET)

97 — CELL NUMBER

GROUND WATER IN STORAGE NOT CALCULATED IF AREA
1) COMPOSED OF NONWATER-YIELDING FRANCISCAN COMPLEX
2) COMPOSED OF SONOMA VOLCANICS WITH HIGHLY VARIABLE WATER-YIELDING CHARACTERISTICS

STATE OF CALIFORNIA
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DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

GROUND WATER IN STORAGE PER CELL
IN THE SONOMA VALLEY

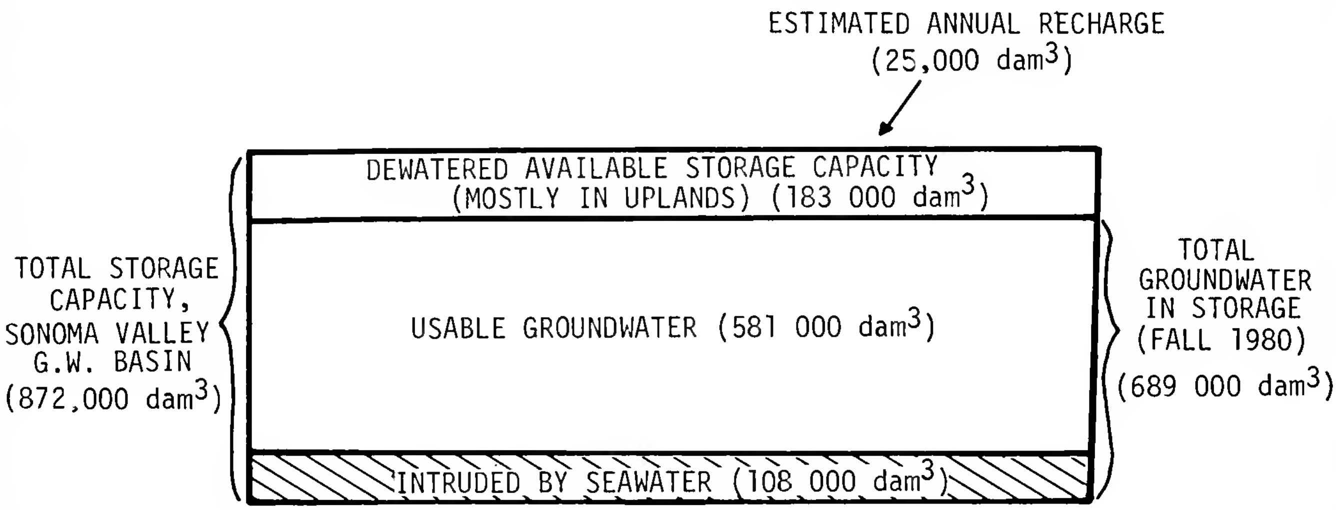
SCALE
1 .5 0 1 2 3 4 5 KILOMETRES
1 .5 0 1 2 3 4 5 MILES

Table 2

GROUND WATER SUPPLY IN THE SONOMA VALLEY

Total Storage Capacity	872 000 dam^3 (708,000 ac-ft)*
Available Storage Capacity	183 000 dam^3 (149,000 ac-ft)
Total Volume of Ground Water in Storage (based on fall 1980 ground water levels)	689 000 dam^3 (559,000 ac-ft)
Volume of Ground Water Seriously Affected by Sea Water Intrusion	108 000 dam^3 (87,000 ac-ft)
Volume of Usable Ground Water in Storage	581 000 dam^3 (472,000 ac-ft)
Estimated Annual Natural Recharge	25 000 dam^3 (20,000 ac-ft)
Percentage of Total Storage Capacity Dewatered	21%

*Because both metric and customary figures have been rounded to the nearest thousand, multiplying metric figures by 0.81070 will not give the customary figures.



The bay mud and alluvial fan deposits are generally affected only to shallow depths of 30 m (100 ft). At present, the total volume of ground water lost in this interval because of intrusion is 108 000 dam^3 (87,000 ac-ft). No attempt was made to calculate the volume of unpotable connate water in other geologic formations in the Sonoma Valley.

In general, available data do not indicate any appreciable change in the volume of ground water affected by sea water intrusion since 1960 (Kunkel and Upson; see Figure 11). One 40-m (130-ft) well near Schellville (5N/5W-28N1) has shown a slow, progressive deterioration in water quality since first sampled in 1951. From 1951 to 1978, chloride ion concentration increased from 85 to 375 mg/L; electrical conductivity (EC) increased from 455 to 1 420 microsiemens per centimetre (µS/cm). This indicates that sea water intrusion in the southern Sonoma Valley is a continuing problem; the volume of affected ground water will probably slowly increase in the future. Periodic ground water quality sampling over a long period of time is needed near the affected area to determine when mitigating measures are needed.

Further Limits on Volume of Usable Ground Water

After removing the volume of ground water degraded by sea water from the total volume of ground water in storage in the Sonoma Valley, there remains 581 000 dam^3 (472,000 ac-ft) of usable ground water in storage as of fall 1980.

Experience has shown that not all this water can be extracted. Sustained yield is the volume of water in storage that can be extracted annually without causing adverse effects on the ground water basin. Sustained yield generally equals average annual recharge to the basin, but can be increased over a short period of time to temporarily remove an additional volume of water beyond seasonal fluctuations. This dewatering creates additional storage space for the recharge of surface water during wet years.

The hydrologic balance of a ground water basin can be described by the hydrologic equation:

Inflow-Outflow = Change in Storage

The "inflow" term in this equation is the volume of water returned to the basin and the "outflow" term is the volume of water removed from the basin. The "change in storage" term represents the change in the volume of ground water in storage which, if greater than zero, is the volume of recharge for that period.

To determine the natural recharge rate, and therefore the sustained yield of the basin, certain data are required that have not been collected in the Sonoma Valley:

1. The volume of water returned to the ground water basin, which includes:
   - Volume of irrigation water that percolates to the ground water body (deep percolation).
   - Volume of streamflow and precipitation that percolates to the ground water body.
   - Measured soil permeabilities.
2. The volume of water removed from the ground water basin, which includes:
   - Volume of ground water pumpage.
   - Volume of surface and subsurface water flowing out of the basin.
   - Volume of water used by vegetation (evapotranspiration).

This type of detailed balance was not attempted during this study because of the lack of data.

A rough estimate of the volume of annual recharge to the Sonoma Valley basin has

been made using the computer program TRANSCAP. The Sonoma Valley was divided in two, with cells 1-142 included in the northern portion and cells 143-169 included in the southern portion (Figure 7). The recharge estimate was made for the northern portion because sea water intrusion limits the use of ground water contained in shallow aquifers in the southern portion. These shallow aquifers would normally provide storage for recharged water.

Hydrographs of wells in the northern portion of the Sonoma Valley generally show an annual fluctuation of 3 m (10 ft) between spring and fall ground water level measurements. Based on TRANSCAP, this fluctuation represents a total volume of 25 000 dam^3 (20,000 ac-ft) of ground water that is withdrawn and naturally recharged every year. Note that this value of recharge was calculated assuming that the ground water levels fluctuated a uniform 3 m (10 ft) in all cells in the northern Sonoma Valley; some wells south of the City of Sonoma are known to have annual fluctuations of less than 3 m (10 ft).

This calculation also assumes that all ground water in the Sonoma Valley is unconfined; some areas in the Sonoma Valley are known to have semiconfined to confined ground water. The portion of all ground water in the study area which is semiconfined to confined is not known. Confinement would reduce the volume of recharge determined from the 3-m fluctuation; the amount of reduction is not known. In determining the area to be included in the recharge calculation, some cells known to contain small amounts of fresh ground water were not included in the northern portion, and a few containing brackish water were included.

Hydrographs indicate that during the 1976-1977 drought, ground water levels were lowered an average of 2 m (7 ft) below the normal low fall level. By spring 1978, most ground water levels returned to normal high spring levels. This 5-m (17-ft) change in ground water levels at the end of the 1976-1977 drought represents a total volume of 40 000 dam^3 (30,000 ac-ft) of recharge if all ground water is unconfined. Therefore, the 25 000 dam^3 (20,000 ac-ft) represents an approximate average volume of annual recharge in the northern Sonoma Valley. The 40 000 dam^3 (30,000 ac-ft) of recharge after a time of unusually low ground water levels indicates that this area is capable of higher annual recharge if there were space in the aquifers to store it. Under present conditions, it appears that natural recharge exceeds the storage capacity; the surplus runs off as "rejected recharge".

The northern Sonoma Valley appears to be capable of recharge that under normal conditions would fill the available storage capacity estimated from TRANSCAP. There may, therefore, be a topographic limit to the volume of natural recharge that can be stored before "leakage" begins. If more than a certain volume of water is recharged, that extra stored water begins to leak out in creeks and roadcuts, and as springs.

Chapter 5. GROUND WATER MOVEMENT IN THE SONOMA VALLEY

The effect of increased ground water extraction on the Sonoma Valley depends on the degree to which aquifers are connected, including the presence or absence of barriers to ground water movement. Aquifer continuity controls the movement of poor quality ground water from one area to another and the extent to which sea water can move into fresh-water aquifers. Aquifer continuity controls the degree of interaction between ground water and fresh surface water and it influences the movement of naturally and artificially recharged water from a recharge site to an area of ground water extraction.

Aquifer Continuity

The degree of aquifer continuity is controlled by two factors: the areal extent of each single aquifer or group of interconnected aquifers, and the influence of faults on ground water. The areal extent of an aquifer or aquifers can be evaluated by examining the surficial and subsurface geology, reviewing ground water quality data to locate similar quality types, and comparing hydrographs for wells of different depths or in different locations. Faults can influence ground water by reducing or increasing transmissivity across the fault plane; the influence of faults on ground water movement can be determined from constant-rate pump tests of water wells and from ground water level maps.

Many geologic units in Sonoma Valley contain discontinuous lenses of water-yielding sands and gravels, while other units consist of nonwater-yielding material. These characteristics result in a number of isolated ground water bodies, each having a unique water quality. These same characteristics also reduce the potential for vertical and horizontal movement of ground water. Ground water movement can be analyzed for local areas in the Sonoma Valley, but because of the number of isolated water bodies, some of which may be semiconfined, basinwide predictions of ground water behavior made with existing data are of questionable value.

To determine the areal extent of the various aquifers in the Sonoma Valley, standard mineral analyses of ground water were evaluated. Standard mineral analyses include the concentrations of the cations calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), and potassium (K^{+}), and the anions bicarbonate (HCO_3^{-}), carbonate ($CO_3^{=}$), sulfate ($SO_4^{=}$), and chloride (Cl^{-}).

In this report, water types are described by listing cations first, in order of abundance in milliequivalents per litre, followed by anions, in order of abundance. A single cation or anion is used to describe a water type if that ion constitutes over 50 percent of the total cations or anions in solution. Closely spaced wells with similar water quality types were assumed to tap the same aquifer. Conversely, it was assumed that aquifer separation exists to the degree that water quality types vary when taken from wells with perforations at the same elevation at different locations, or different elevations at the same location.

Ideally, ground water quality data collected entirely within a single year should be used to evaluate regional water quality because the chemical composition of ground water can change slowly over time. Water quality data for the Sonoma Valley are sparse and were collected sporadically over 30 years. In some cases, several analyses have been collected for

the same well. In determining regional ground water quality patterns, the most recent data have been given the most weight.

Wells pumping from the same aquifer, even if at different elevations or in different locations, usually will have similar water level fluctuations shown on well hydrographs. The few long-term hydrographs available in the Sonoma Valley were examined for such similarities (see below).

Aquifer continuity is described by geologic units because each unit has distinct properties controlling the occurrence of ground water (see Plate 1 and Figures 5A-E).

Bay Mud Deposits

The few water-yielding zones in the bay mud deposits generally lack vertical and horizontal connection. Water in the bay mud deposits is generally brackish and of poor quality, varying from sodium chloride to magnesium sodium chloride in character. Bicarbonate ion is present in water from many wells, and increases with depth. All the water is highly mineralized.

Near the edge of the sea water intrusion front, ground water in bay muds is often highly mineralized, but lacks chloride ion; sodium bicarbonate water is found in cells 133 (5N/5W-20R1), 137 (5N/6W-25P1), and 140 (5N/5W-28R1) (Figure 7). This water quality type may represent an initial stage of intrusion.

The great variation in water quality types indicates a lack of any significant aquifer continuity within the bay muds. No hydrographs are available for the few shallow wells that pump from bay mud deposits, so no evaluation of the aquifer continuity between bay muds and alluvial fan deposits can be made. Although the amount of aquifer continuity is assumed to be small, under heavy pumping in fan deposits, some brackish water may be drawn from bay mud deposits into the alluvial fans.

Alluvial Fan Deposits and Alluvium

Alluvial fan deposits are present in three areas within the study area, and the geologic and hydrologic properties of the deposits vary slightly from place to place.

In the Bennett Mountain area, the alluvial fan deposits form essentially one aquifer. Wells pumping from these deposits all have similar water quality -- varying amounts of calcium, magnesium, and sodium in combination with bicarbonate. Water from wells that pump from both the fan deposits and the Sonoma Volcanics has a similar quality. This may indicate continuity between aquifers in these different geologic units.

In the vicinity of Glen Ellen and near the City of Sonoma, the alluvial fan deposits form essentially one aquifer. Ground water quality is similar to that in the Bennett Mountain area, but contains more calcium and magnesium and less sodium. Sodium concentration increases with depth, while calcium and magnesium concentrations decrease.

Shallow (less than 60 m or 200 ft in depth) and deep (greater than 60 m or 200 ft in depth) wells generally have similar fluctuations. Deep wells usually have a larger annual fluctuation in water level than do shallow wells. Near the City of Sonoma, a 21-m (70-ft) deep well (cell 127, 5N/5W-17C1) has an annual fluctuation of 1.5 m (5 ft) and a 75-m (245-ft) deep well (cell 120, 5N/5W-8P2) has an annual fluctuation of about 6 m (20 ft). A third 41-m (133-ft) deep well (cell 126, 5N/5W-18R1) has an annual fluctuation of about 3 m (10 ft), intermediate in magnitude between the other two. Two wells, both about 52 m (170 ft) deep (cells 131 and 100, wells 5N/6W-2N2 and -24M1), have similar depths to the

ground water table and similar magnitudes of fluctuation, indicating a common aquifer.

In the vicinity of Schellville, aquifer continuity within the alluvial fan deposits is not as great as in other portions of the study area. Since alluvial fan deposits are finer grained at the southern end of the Sonoma Valley, aquifers tend to be more discontinuous in this area. Water from wells south of the City of Sonoma generally varies more in quality than is common in other areas. Some wells near Sonoma Creek, such as one in cell 145 (5N/5W-31B1), have been intruded by sea water. Similarities in hydrographs from wells in this area may result from the influence of San Pablo Bay tides.

A ground water elevation map of the study area was drawn based on fall 1980 water levels in shallow wells pumping from alluvial fan deposits (Figure 10). Water levels in wells pumping from both alluvial fan deposits and underlying materials were not used, because these levels are generally lower and more variable than levels in wells drawing only from fan deposits.

Glen Ellen Formation

In the Sonoma Valley, only limited water quality or water level data are available for wells pumping water from the Glen Ellen Formation. In general, aquifers in the Glen Ellen Formation are more discontinuous than aquifers in alluvial fan deposits, because the Glen Ellen is more clay-rich and consolidated.

North of Glen Ellen (cell 70), three wells about 60 m (200 ft) deep contain chloride ion. In the Sonoma Valley, chloride is normally only found where units have been intruded by sea water, or in wells that produce water from the Sonoma Volcanics. The source of the chloride near Glen Ellen is unknown but chloride concentration increases to the south.

Petaluma Formation

The Petaluma Formation has variable water quality and degrees of aquifer continuity. Since the Petaluma is a marine formation, it frequently contains brackish connate water that is highly mineralized. In the Sonoma Valley, water quality or water level data are not available for wells that pump water from the Petaluma Formation. Data from well drillers' reports indicate that the Petaluma Formation contains only a few, discontinuous aquifers. In the Petaluma Valley, the Petaluma Formation generally contains bicarbonate ground water with varying percentages of calcium, magnesium, and sodium.

Other Geologic Units

Because of the variable geology of the Sonoma Volcanics, it was not possible to determine the extent of aquifer continuity within its permeable units. In the Bennett Mountain area, chlorides concentrations are low or absent in water from the Sonoma Volcanics; in the Sonoma Valley study area, water from the Sonoma Volcanics usually contains higher concentrations of chlorides. Chloride concentration ranges from 4.5 milligrams per litre (mg/L)(7N/7W-15C1) up to 392 mg/L in thermal water from a well drilled for the Boyes Hot Springs Bathhouse (5N/6W-2A2). Most wells have chloride concentrations under 100 mg/L. The absence and presence of chlorides may indicate a lack of aquifer continuity between permeable units in the Sonoma Volcanics in these two areas. Ground water in the Sonoma Volcanics is frequently confined or semiconfined. Most ground water is of good quality except where thermal.

The Franciscan complex in the study area contains water only in fractures; the extent of aquifer continuity depends on the extent those fractures are connected. The extent of fracture interconnection was not determined. No information is available for aquifers in the Neroly Formation.

Faults

No major faults have been mapped within the alluvial fan deposits, which form the principal water-yielding geologic unit in the Sonoma Valley. Minor concealed faults in fan deposits near Glen Ellen apparently have little effect on ground water. Some faults have been mapped in the Glen Ellen Formation, which produces only low yields of ground water. Many faults have been mapped in the Sonoma Volcanics and the Franciscan complex; the effect of these faults on ground water in these geologic units is unknown.

Surface Water and Ground Water Divide

A hydrologic divide separates the Bennett Mountain area from the Sonoma Valley study area (Plate 1). Streams on the Bennett Mountain side of the divide flow into Santa Rosa Creek and then into the Russian River. Streams on the Sonoma Valley side of the divide flow into Sonoma Creek and then into San Pablo Bay.

This divide reflects a buried ridge of Sonoma Volcanics (see geologic cross section A-A', Figure 5B). Alluvial fan deposits and the Glen Ellen Formation have been deposited over this ridge. Layers of materials within these two units (such as sand and gravel) generally conform to the now-buried topography of the volcanic rocks. Therefore, since layers dip away from the center of the buried ridge, ground water will also tend to flow away from the buried ridge. For this reason, ground water in the Bennett Mountain area and Sonoma Valley tends to behave independently. Ground water in the Bennett Mountain area is likewise isolated from ground water in the Santa Rosa Plain by a similar buried ridge of volcanic rocks east of the City of Santa Rosa (see area near Melita on section A-A', Figure 5B).

Sea Water Intrusion

In the past, sea water intrusion has affected the few aquifers present in bay mud deposits and aquifers in alluvial fan deposits. Kunkel and Upson (1960) described one well (5N/5W-31A3) that showed signs of sea water intrusion when sampled in late summer or fall; the well had acceptable quality in spring, after winter rainfall flushed the sea water from the aquifer it tapped. This well is within the area that Kunkel and Upson described as intruded.

Bay mud deposits were deposited in a marine environment, and much sea water was trapped in the fine-grained sediments at that time. In general, little fresh water has moved through the deposits since deposition, so the deposits contain highly mineralized, brackish water. In addition, some wells near San Pablo Bay produce magnesium and sodium chloride water even closer to the composition of sea water, as a result of postdepositional inland sea water movement. Because these deposits are fine-grained, water moves through them slowly, and the movement of sea water into the deposits should remain a localized phenomenon. Because of the generally poor quality of water in the bay mud deposits, water contained in these deposits was not included in estimates of the volume of usable ground water in the Sonoma Valley (Chapter 4).

Alluvial fan deposits in the southern part of the Sonoma Valley study area near San Pablo Bay have suffered post-depositional sea water intrusion. These fans were originally deposited by fresh-water streams flowing from hills onto flatlands; they normally contain fresh water. Near San Pablo Bay, however, ground water pumping in fan deposits creates a landward gradient, drawing brackish water from tidal creeks and bay mud deposits into fan deposits. Since fan

deposits are coarser grained than bay mud deposits, the potential for inland movement is greater. Since fan deposits become progressively more coarse-grained to the north within the Sonoma Valley study area, the speed of movement would likewise increase up-valley.

The well cited in the first paragraph is one example of intrusion in fan deposits. Another is well 5N/5W-28N1, within the area known to be intruded, which has undergone a slow, progressive deterioration in quality from 1951 to 1978.

Ground water quality data are sparse for the southern Sonoma Valley study area. Data for wells in areas known to be intruded indicate quality deterioration. Some wells near but outside the intruded areas mapped by Kunkel and Upson, such as 5N/5W-20R1, have improved in quality over the last 20 years; the EC of water from this well has dropped from 1 160 µS/cm in 1958 to 823 µS/cm in 1975.

Data are not sufficient to redraw the line shown by Kunkel and Upson in 1960 as delineating the extent of sea water intrusion (Figure 13). Increased ground water quality sampling in shallow wells (less than 60 m or 200 ft deep) near the present sea water intrusion front is necessary to monitor inland movement of sea water. Locations for increased quality monitoring are described in Chapter 8.

Natural and Artificial Recharge

Natural recharge is the movement of water from land surfaces and streambeds into underlying aquifers. Because aquifers in the Sonoma Valley are generally full at present, recharge occurs in response to natural subsurface outflow or pumpage of ground water from those aquifers. Several physical factors control the potential natural recharge rate in an area:

° Slope of the land surface.

° Permeability of the soils.

° Subsurface geology.

° The amount of available storage space in the aquifer.

A rough estimate of the annual volume of natural recharge is presented in Chapter 4.

For recharge to take place in an area, the slope of the land surface should be less than 15 percent and the infiltration rate of the soil profile should exceed 1.5 centimetres (0.6 inch) per hour (Muir and Johnson, 1979). If the slope is greater than 15 percent, rapid runoff greatly reduces the recharge potential. For an appreciable amount of water to penetrate the soil, the infiltration rate must be rapid.

Subsurface geology is important in evaluating a recharge area and is the most difficult factor to evaluate. Good aquifer continuity between the area of recharge and the area of extraction is necessary. The extent of aquifer continuity in the Sonoma Valley has already been discussed in this chapter. The ground water level measurement network now being implemented by the Department of Water Resources and the Sonoma County Water Agency will provide more information on the continuity of aquifers. Other data that would aid in determining water movement would be:

° 24-hour constant-rate pump tests to determine aquifer transmissivity.

° Drilling at potential artificial recharge sites to determine detailed local subsurface geology.

The amount of available storage in any aquifer at any location determines whether recharge can take place at that location. Without storage space avail-

able in the underlying aquifer, surface water will run off the most favorable recharge site as "rejected recharge". Figure 7 shows areas of favorable slope and soils within the study area and estimates of available storage as of fall 1980 in aquifers within each cell.

Soils with slopes and permeabilities suitable for natural and artificial recharge cover 2 900 hectares (7,200 acres) in the Sonoma Valley study area -- 7 percent of the total land surface (Figure 7). An additional 2 600 hectares (6,500 acres) are covered with soils of suitable permeability; they can be classified as recharge areas if the land slope is less than 15 percent.

The most significant natural recharge takes place in the stream channels incised in alluvial fan deposits. Alluvial fan deposits in the Sonoma Valley study area are not usually permeable enough to act as recharge areas, although some slow infiltration of rainwater through fan deposits does take place. Some fan deposits in the Bennett Mountain area are flat and permeable enough to be recharge areas. Since the alluvial fan deposits, both in and outside of stream channels, are usually interconnected, ground water can move from recharge areas into areas of ground water pumpage.

Although TRANSCAP and water level data indicate storage space is available for recharged water in many areas in the Bennett Mountain area and Sonoma Valley, the volume of water available for recharge has historically exceeded the storage space available for it. When this happens, the excess water runs off as streamflow. Kunkel and Upson (1960) described Sonoma Creek as a gaining stream, fed by discharging ground water. Ground water levels in the valleys recovered rapidly from the 2-year 1976-1977 drought; by spring 1978, most valley wells had recovered 5 m (17 ft) to normal high spring levels from low fall 1977 levels. If ground water use was increased near Sonoma Creek, higher than normal natural recharge from the creek should maintain ground water at present levels. Care should be taken to avoid increased pumpage near tidal portions of the creek, where surface water quality is poor, or near areas of known sea water intrusion.

Many areas of permeable soils blanket the mountains on the east and west sides of the study area. Permeable soils tend to form on Sonoma Volcanics, especially the sedimentary units (labeled Tst on Plate 1). If the slopes are less than 15 percent, these soils are classified as potential recharge areas. Since aquifers in the Sonoma Volcanics are discontinuous, the fate of the recharged water is difficult to determine. Similarly, some areas in the Glen Ellen Formation are recharge areas. Since aquifers in the Glen Ellen Formation are usually discontinuous, the fate of recharged water is also not known.

In mountainous areas, recharge from rain or streams occurs where an aquifer is exposed at the surface. Recharged ground water then moves down dip in the aquifer (Figure 12) until:

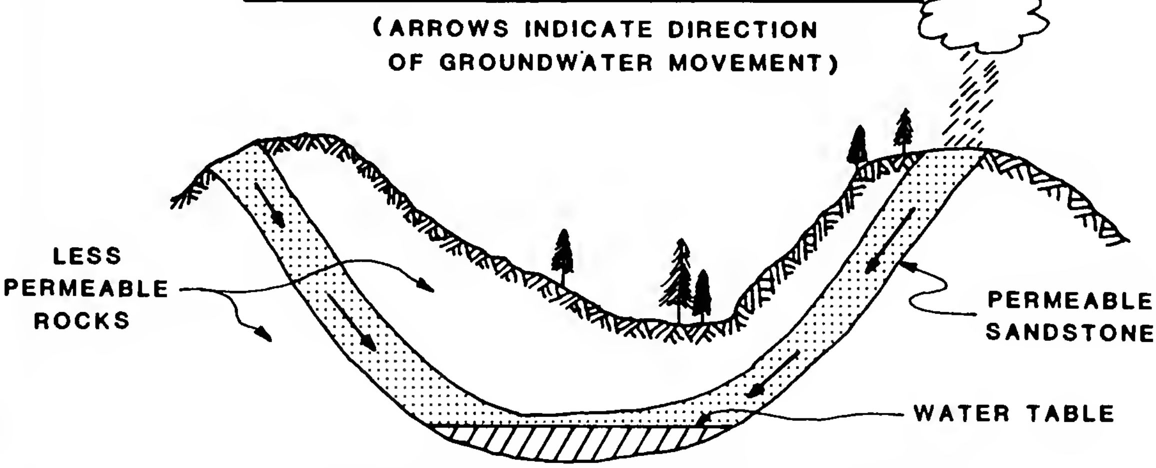
- The water reaches the lowest point in elevation, where it remains.
- The aquifer again is at the land surface, where ground water is released as a spring.
- Ground water encounters a barrier, which reduces the flow rate.

When aquifers are as discontinuous as those in the mountainous portions of the study area, ground water frequently does not reach the area of ground water extraction because of these geologic complexities.

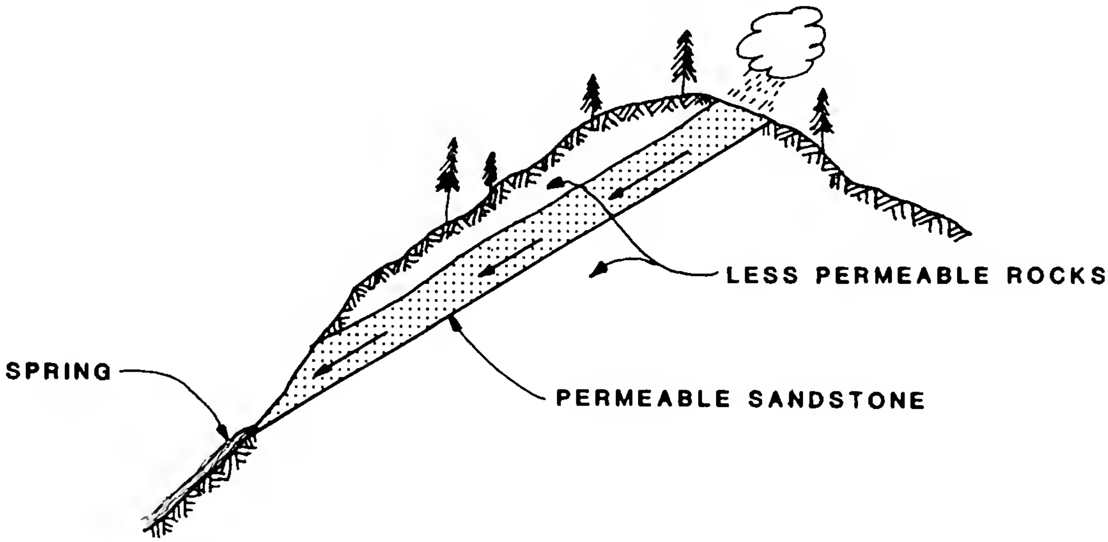
At present, artificial recharge is not necessary in the Sonoma Valley and Bennett Mountain area because the basins

MOVEMENT OF GROUND WATER

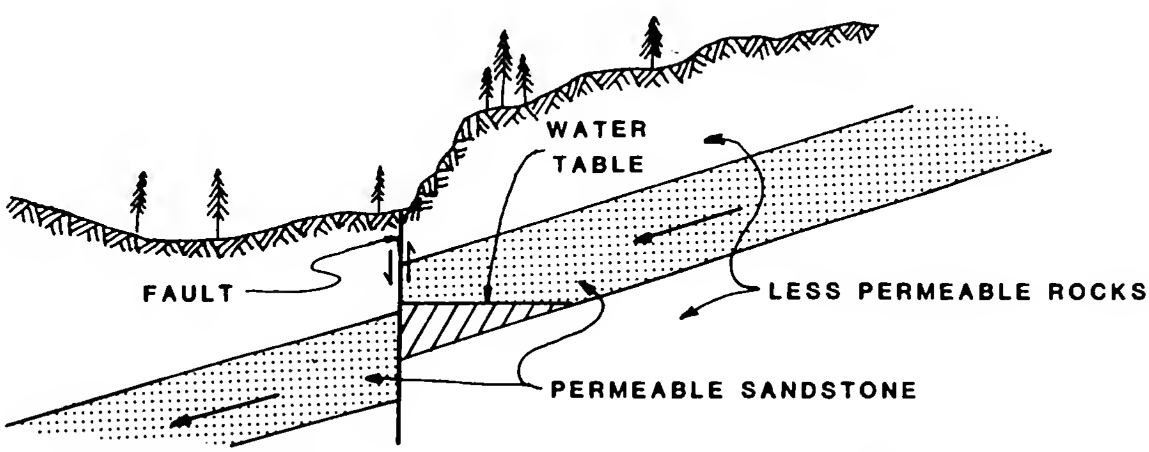
(ARROWS INDICATE DIRECTION OF GROUNDWATER MOVEMENT)



GROUND WATER MOVES DOWNDIP UNTIL IT REACHES THE LOWEST POINT IN ELEVATION



GROUND WATER MOVES DOWNDIP UNTIL THE PERMEABLE ROCKS ARE AGAIN AT THE SURFACE GROUND WATER IS RELEASED AS A SPRING



TRANSMISSIVITY IS REDUCED ACROSS FAULT GROUND WATER "STACKS UP" ON UPHILL SIDE OF FAULT

are essentially full and because surface water is available to meet most domestic needs. When the basin has been dewatered sufficiently to make an artificial recharge program feasible, the recharge site(s) selected should be in an area of favorable slope and soil permeability. A detailed subsurface geologic investigation should be conducted for the proposed site, including on-site drilling and evaluation of the degree of connection between the recharge area and the area of extraction. An artificial recharge program to halt or reverse sea water intrusion should be considered if further water quality sampling indicates continuing inland movement of sea water.

Chapter 6. SOURCE AND POTENTIAL MIGRATION OF SELECTED MINERAL CONSTITUENTS

There are many ions and substances that can, when present above certain concentrations in ground water, be harmful to humans, animals, or plants. Increased ground water pumpage near areas with water quality problems may cause the water containing thése constituents to migrate.

Summary

Sodium, salinity, total dissolved solids (TDS), boron, nitrate, hardness, iron and manganese concentrations in ground water were examined during this study. High sodium, salinity, TDS, and boron frequently occur together, most commonly in wells affected by sea water intrusion or in thermal water. High boron and sodium frequently are found together in the Glen Ellen area; the boron and sodium may be related to faulting or to the Sonoma Volcanics.

Ground water in the Sonoma Valley has not been systematically analyzed for nitrates in the past; only one well of the 50 sampled contained nitrates in excess of recommended limits. Further sampling of nitrates is needed to determine the source and extent of contamination.

Hardness increases from north to south in the study area, and generally decreases with depth. Ground water in the Bennett Mountain area and northern Sonoma Valley is generally soft. Near the City of Sonoma, the alluvial fan deposits, which form the major water-yielding unit in this area, produce moderately hard water. Geologic units affected by sea water intrusion generally produce hard water.

Few accurate analyses are available for iron and manganese; available data indicate that water containing iron and manganese above recommended limits is produced from wells:

° Tapping alluvial fan deposits.
° Tapping the Glen Ellen Formation.
° Tapping the Sonoma Volcanics.

The potential for movement of ground water with these quality problems varies. The area of greatest concern is in alluvial fan deposits at the southern end of the study area. Although fan deposits are finer grained in this area than to the north, pumping near areas intruded by sea water could induce landward movement of sea water into fan deposits. Water quality degradation caused by intrusion may include increased sodium, salinity, total dissolved solids, boron, hardness, and iron and manganese. Generally, the potential for movement of poor quality water is highest within alluvial fan deposits, but fan deposits generally contain the best quality water. Poor quality water within other formations, such as the Glen Ellen and Sonoma Volcanics, moves slowly because permeability within the formations is low.

Sodium

High concentrations of sodium ion may be hazardous to persons with heart problems such as high blood pressure. While generally not hazardous to livestock, high concentrations of sodium ion can adversely affect agriculture by causing soils to deflocculate or "puddle"; a hard crust forms after irrigating, adversely affecting tilth, permeability, and infiltration.

Based on the University of California Committee of Consultants report, "Guidelines for Interpretation of Water Quality for Agriculture" (Ayers and Branson, 1975), the adjusted sodium adsorption

ratio (ASAR) is used to evaluate the effect of sodium on agriculture. The ratio is computed by the following formula:

$$ASAR = \frac{Na^{+}}{\sqrt{1/2\,(Ca^{++} + Mg^{++})}} \left[1 + (8.4 - pHc)\right]$$

where pHc is a calculated value based on the concentration of total cations, $Ca^{++} + Mg^{++}$, and $CO_3^{=} + HCO_3^{-}$, all expressed in milliequivalents per litre (see Ford, 1975, Table 20).

For ion toxicity from root absorption, problems increase as the ASAR exceeds 3; severe problems occur when the ASAR is greater than 9 (Ayers and Branson, 1975). For ion toxicity from foliar absorption, problems increase as the ASAR exceeds 3. Foliar absorption limits are important when sprinklers are used for irrigation or frost control. Previous guidelines for sodium used the ASAR in conjunction with electrical conductivity (after Hem, 1959). The new guidelines have a lower threshold than the previous guidelines.

Of 54 wells analyzed for sodium in the Sonoma Valley, 31 were found to have ASAR values exceeding 3; 18 have ASAR values exceeding 9 (Table 3 and Figure 13A). Of the 31 wells, 14 had been similarly identified in DWR Bulletin 118-4, Volume 1 (Ford, 1975), using Hem. Water from the affected wells does not represent a single quality type, although sodium is generally the dominant cation. Boron is frequently associated with high sodium.

The highest sodium is in the southern portion of the Sonoma Valley, in water from aquifers that have been intruded by sea water. High sodium is already widespread in this area; because the sediments are generally fine-grained, the potential for migration is low except within coarser grained alluvial fan deposits that have been intruded. The possibility of movement is high in the intruded fan deposits if the sea water intrusion is allowed to spread.

One well in cell 109 (5N/6W-2A2), which draws water from the Sonoma Volcanics, produces highly mineralized thermal water that poses a severe sodium problem. Other wells drilled in Sonoma Volcanics in this area may pose similar quality problems.

Several wells in cells 48 and 70 (6N/6W-5L3, -16B2, and -16H1), which draw water from the Glen Ellen Formation, produce water that poses a severe sodium problem. The poor quality may be the result of base exchange within clays, which increases the sodium concentration and decreases the calcium and magnesium concentrations. Since high boron concentrations are also associated with these wells, the poor quality may also be associated with faulting or movement of water from the Sonoma Volcanics. The potential for migration of this poor quality water is low because the clay-rich and consolidated nature of this formation ensures low permeability.

Salinity

Excessive salinity in water can kill sensitive plants and impart a salty taste to drinking water. The degree of salinity hazard is determined in different ways for agricultural and domestic water. Salinity of agricultural water supplies is measured by electrical conductivity and chloride ion concentration; salinity of domestic water supplies is measured by chloride ion concentration.

In agriculture, salinity problems from root absorption are related to electrical conductivity (EC). Problems increase as the EC exceeds 750 microsiemens per centimetre (uS/cm). Problems are severe when the EC exceeds 3 000.

A related problem in agriculture is ion toxicity caused by high levels of chloride ion. Problems from foliar absorption increase as the chloride ion concentration exceeds 106 mg/L. Problems from root absorption increase as the chloride ion concentration exceeds

Table 3

SODIUM IN GROUND WATER
IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	Depth (feet)	Date of Sampling mo/yr	Adjusted SAR Value[1]	Degree of Hazard: Increasing	Degree of Hazard: Severe
4N/5W-2Q2	91	(300)	3/59	12.6		x
-14D2	494	(1620)	7/73	17.7[2]		x
-28P1	--	(---)	10/60	29.5		x
-28Q1	--	(---)	8/54	25.35[2]		x
-34D1	61	(200)	4/62	25.7[2]		x
5N/5W-8P2	75	(245)	8/74	7.5	x	
-9M2	78	(257)	1/51	12.4[2]		x
-18D2	23	(75)	3/65	4.7	x	
-20R1	154	(504)	7/70	22.0[2]		x
-28N1	40	(130)	8/58	3.2	x	
-28R1	85	(280)	7/71	20.7		x
-31A1	124	(408)	4/52	26.2[2]		x
-31A3	17	(56)	8/54	25.6[2]		x
-31B1	17	(56)	9/57	13.2[2]		x
-33K1	58	(190)	9/60	49.9[2]		x
5N/6W-2A2	107	(350)	8/58	20.7[2]		x
-12F1	34	(113)	8/58	4.9	x	
-12M1	--	(---)	8/72	3.9	x	
-25P1	52	(171)	8/58	12.9		x
-25P2	195	(640)	7/70	14.2		x
6N/6W-5L1	41	(133)	9/57	8.9	x	
-5L3	2	(6)	5/52	10.0		x
-16B2	64	(211)	9/51	13.4[2]		x
-16H1	64	(211)	5/51	11.8[2]		x
-16J2	--	(---)	10/49	6.6	x	
-23M2	71	(233)	3/65	6.3	x	
-26E1	93	(304)	8/58	7.6[2]	x	
-27A1	71	(233)	4/61	5.2	x	
6N/7W-17D1	--	(---)	1/57	9.1		x
-17E1	198	(650)	9/63	10.2[2]		x
7N/6W-29P1	34	(112)	1/57	3.4[3]	x	
7N/7W-32G1	123	(403)	10/51	5.9	x	

1/ All exceed recommended limit of ASAR = 3. Sodium hazard rated "severe" if ASAR >9.
2/ Well described in DWR Bulletin 118-4, Volume 1 (Ford, 1975).
3/ Subsequent samples show ASAR <3.

142 mg/L; problems are severe when the concentration exceeds 355 mg/L (Ayers and Branson, 1975).

The salinity of domestic water supplies is measured by the concentration of chloride ion. Title 22 of the California Administrative Code (California Department of Health, 1977) recommends a maximum concentration of chloride ion in drinking water of 250 mg/L; the maximum allowable concentration is 500 mg/L. Water containing more than 250 mg/L of chloride ion usually has a noticeably salty taste.

Of the 84 wells evaluated for salinity in the Sonoma Valley, 25 produce water with electrical conductivities greater than 750 µS/cm; 7 exceed 3 000 uS/cm. Of the 83 wells tested for chloride ion, 23 produce water with chloride ion concentrations greater than 106 mg/L and 17 exceed 142 mg/L; 12 exceed 250 mg/L and 8 exceed 500 mg/L (Table 4 and Figure 13B).

In the Sonoma Valley, ground water with high electrical conductivity is generally found in areas affected by sea water intrusion or in rocks of the Sonoma Volcanics. Two wells in alluvial fan deposits (cell 121, well 5N/5W-9N1; and cell 118, well 5N/6W-12F1) produce water with electrical conductivities exceeding 900 µS/cm; the source of the salinity is unknown. Several wells near the area affected by sea water intrusion have electrical conductivities in excess of 1 000 µS/cm (5N/5W-20R1 and -28R1); their water, although highly mineralized, does not contain the high chloride ion concentration characteristic of sea water intrusion.

The potential for movement of water known to have high salinity varies with the source of the salinity. Wells drilled into rocks of the Sonoma Volcanics in areas where the volcanics are known to contain saline ground water will generally produce saline ground water. Because of the discontinuous nature of the Sonoma Volcanics, wells drilled else-

Table 4

SALINITY OF GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	Depth (feet)	Date mo/yr	Chloride mg/L	Electrical conductivity[5/] µS/cm
4N/5W-2Q2	91	(300)	8/58	139[2/]	1 040
			3/59	135[2/]	1 050
-14D1	--	(--)	3/50	121[2/]	957
-14D2	494	(1620)	10/60	148[2,3/]	1 071
			9/63	122[2/]	1 260
-14L1	--	(--)	3/50	203[2,3/]	1 220
-28P1	--	(--)	9/61	2 850[1,2,4/]	9 190
-28Q1	--	(--)	8/54	808[1,2,4/]	3 310
-32B1	--	(--)	2/50	314[1,2,3/]	1 880
-32C1	--	(--)	2/50	896[1,2,4/]	3 400
-34D1	61	(200)	4/61	643[1,2,4/]	2 990
			4/62	730[1,2,4/]	2 910
5N/5W-9N1	--	(--)	8/57	90	908
-20R1	154	(504)	9/59	141[2/]	1 240
-28N1	40	(130)	8/78	375[1,2,4/]	1 420
-28R1	85	(280)	7/79	91	1 120
-31A1	124	(408)	6/52	66	957
-31A2	30	(100)	6/52	1 580[1,2,4/]	5 380
-31A3	17	(56)	8/54	1 360[1,2,4/]	4 710
-31B1	17	(56)	9/57	1 480[1,2,4/]	5 010
-31H1	--	(--)	4/52	234[2,3/]	1 310
-33K1	58	(190)	9/60	7 582[1,2,4/]	20 571
5N/6W-2A2	107	(350)	6/57	378[1,2,4/]	1 550
-2A3	--	(--)	6/51	273[1,2,3/]	1 220
-2A4	--	(--)	6/51	208[2,3/]	1 050
-2A5	--	(--)	6/51	132[2/]	901
-12F1	34	(113)	6/75	139[2/]	821
			7/79	120[2/]	908
6N/6W-10G1	--	(--)	6/51	164[2,3/]	1 310
-26R1	--	(--)	4/52	121[2/]	---

Chloride ion concentration:
1/ exceeds 250 mg/L (recommended limit, human drinking water)
2/ exceeds 106 mg/L (increasing problems, agriculture-foliar absorption)
3/ between 142-355 mg/L (increasing problems, agriculture-root absorption)
4/ exceeds 355 mg/L (severe problems, agriculture-root absorption)
Electrical conductivity:
5/ exceeds 750 µS/cm (increasing problems, agriculture-root absorption)

where in the Sonoma Volcanics may or may not produce highly saline ground water.

The potential for movement of saline water within the bay mud deposits is low because the deposits are mostly clay. Potential for movement of saline water into fan deposits at the southern end of the Sonoma Valley study area is greater. Although these southern fan deposits are finer-grained than fan deposits in other parts of the Sonoma Valley and Bennett Mountain area, ground water pumping can create a landward gradient, which would draw sea water inland. Salinity will increase within alluvial fan deposits as sea water moves inland.

Total Dissolved Solids

The amount of total dissolved solids (TDS) in water indicates the total mineral content in the water. The recommended limit for TDS in domestic water is 500 mg/L. The maximum limit for TDS is 1 000 mg/L, although for short periods of time 1 500 mg/L is allowed (California Department of Health, 1977). Water with a TDS higher than 500 mg/L may also be expected to contain other hazardous ions, usually high sodium and salinity.

Of the 59 wells evaluated for TDS in the Sonoma Valley, 15 produce water with TDS greater than 500 mg/L: 7 of these exceed 1 000 mg/L (Table 5 and Figure 13C). Most of these wells also produce water that exceeds recommended limits for salinity, sodium, and boron. The source of the poor quality water is similar to the source of salinity, and is usually related to sea water intrusion or rocks of the Sonoma Volcanics. Potential for movement is the same as that for highly saline water.

Nitrate

High concentrations of nitrate can cause methemoglobinemia, an oxygen deficiency in infants. For this reason, a recommended drinking water limit of 45 mg/L of nitrate (10 mg/L expressed as nitrogen) has been established by the California Administrative Code, Title 22 (California Department of Health, 1977).

Table 5

TOTAL DISSOLVED SOLIDS (TDS) IN GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth: metres	Depth: (feet)	Date: mo/yr	TDS: mg/L*
4N/5W-2Q2	91	(300)	8/58	610
-14D2	494	(1620)	4/62	665
-28P1	--	(--)	9/59	2 750
-28Q1	--	(--)	8/54	1 870
-34D1	61	(200)	4/62	1 620
5N/5W-20R1	154	(504)	9/59	734
-28N1	40	(130)	8/72	583
-28R1	85	(280)	7/71	615
5N/5W-31A1	124	(408)	5/54	585
-31A3	17	(56)	8/54	2 590
-31B1	17	(56)	9/57	2 800
-33K1	58	(190)	9/60	13 167
5N/6W-2A2	107	(350)	--	845
-2A5	--	(--)	--	766
-12F1	34	(113)	7/73	2 908

* All exceed recommended limit of Total Dissolved Solids = 500 mg/L.

Nitrates are produced by aerobic stabilization of organic nitrogen. The presence of nitrate in ground water is usually indicative of pollution from surface sources such as septic-tank leach-fields, fertilizers, or livestock and poultry farms.

Although nitrate contamination of ground water is documented in some areas in the Petaluma Valley, little water quality testing for nitrates has been done in the Sonoma Valley. Of the 50 wells sampled, only one well, 5N/5W-18D2, has been identified as producing water containing nitrate above the recommended limit of 45 mg/L of nitrate (66 mg/L of nitrate, sampled in September 1959)(Figure 13C). Nitrate concentrations in water from nearby well 5N/5W-19L1 are between 10 and 25 mg/L of nitrate (sampled between September 1951 and September 1959). These concentrations are below the recommended limit but are high enough to be of concern. Water from another nearby well (5N/5W-20R1) of similar depth has low concentrations of nitrate (less than 2 mg/L, sampled between March 1958 and August 1969). These data indicate a localized nitrate contamination problem, but further sampling is needed to determine the extent and source of the nitrate.

Boron

Boron in drinking water is not generally considered a health hazard because concentrations up to 30 mg/L are not considered harmful to humans. Although a minor constituent of most water, boron is extremely important in agriculture. An amount greater than 2 mg/L is toxic to most plants, but small amounts of boron are essential to plant growth. Boron is toxic to many plants, such as citrus, grapes, apples, and walnuts, in concentrations of less than 1 mg/L. Boron concentrations below 0.5 mg/L are satisfactory for all crops (Ayers and Branson, 1975).

Of the 55 wells tested in the Sonoma Valley, 28 produce water with boron concentrations greater than 0.5 mg/L, and 13 of these 28 wells produce water with boron in excess of 2.0 mg/L (Table 6 and Figure 13D).

The source of the boron-rich ground water varies within the Sonoma Valley. High boron in the Glen Ellen area (such as well 6N/6W-16B2) may be related to extensive faulting in the area; boron-rich ground water rises toward the surface along the fault planes. Some high boron may have moved into alluvial deposits from the Sonoma Volcanics, as in wells 6N/6W-23M2 and -26E1. Boron-rich ground water in the area south of Schellville is related to sea water intrusion. The source of high boron in wells (such as 5N-5W/31A1 near the City of Sonoma) that pump water from alluvial fan deposits is not known.

The water quality type of all boron-rich water is very similar. Almost all wells with high boron have sodium as the dominant cation and bicarbonate as the dominant anion. Boron-rich water from two wells (5N/5W-20C1 and 5N/6W-13K1) that contain calcium and magnesium instead of sodium as the dominant cation do contain some sodium. Boron-rich water from one well (5N/6W-2A2) that contains chloride instead of bicarbonate as the dominant anion is an atypical thermal sodium chloride water produced from the Sonoma Volcanics.

In the Sonoma Valley, high concentrations of boron in ground water are often associated with water having a moderate-to-severe sodium hazard and high TDS. The potential for migration of boron-rich ground water is the same as for water containing high sodium or TDS.

Hardness

Ground water containing calcium and magnesium salts is divided into two

general classifications· carbonate hardness and noncarbonate hardness. Carbonate hardness becomes apparent after water has been heated, causing the soluble calcium and magnesium bicarbonates to precipitate as insoluble carbonates. The precipitates adhere to heated surfaces, such as the inside of water heaters and hot water pipes, and ultimately reduce the capacity of the fixture. Noncarbonate hardness is not affected by heat, because it is principally caused by the presence of calcium sulfate; since few analyses of noncarbonate hardness are available in the study area, it will not be discussed here. Both forms of hardness reduce the cleansing ability of many soaps and detergents.

The hardness of ground water is variable. Soft waters are those with a hardness of less than 60 mg/L of calcium carbonate; moderately hard waters are those with a hardness range of from 61 to 200 mg/L. Hard waters are those that have a hardness in excess of 200 mg/L.

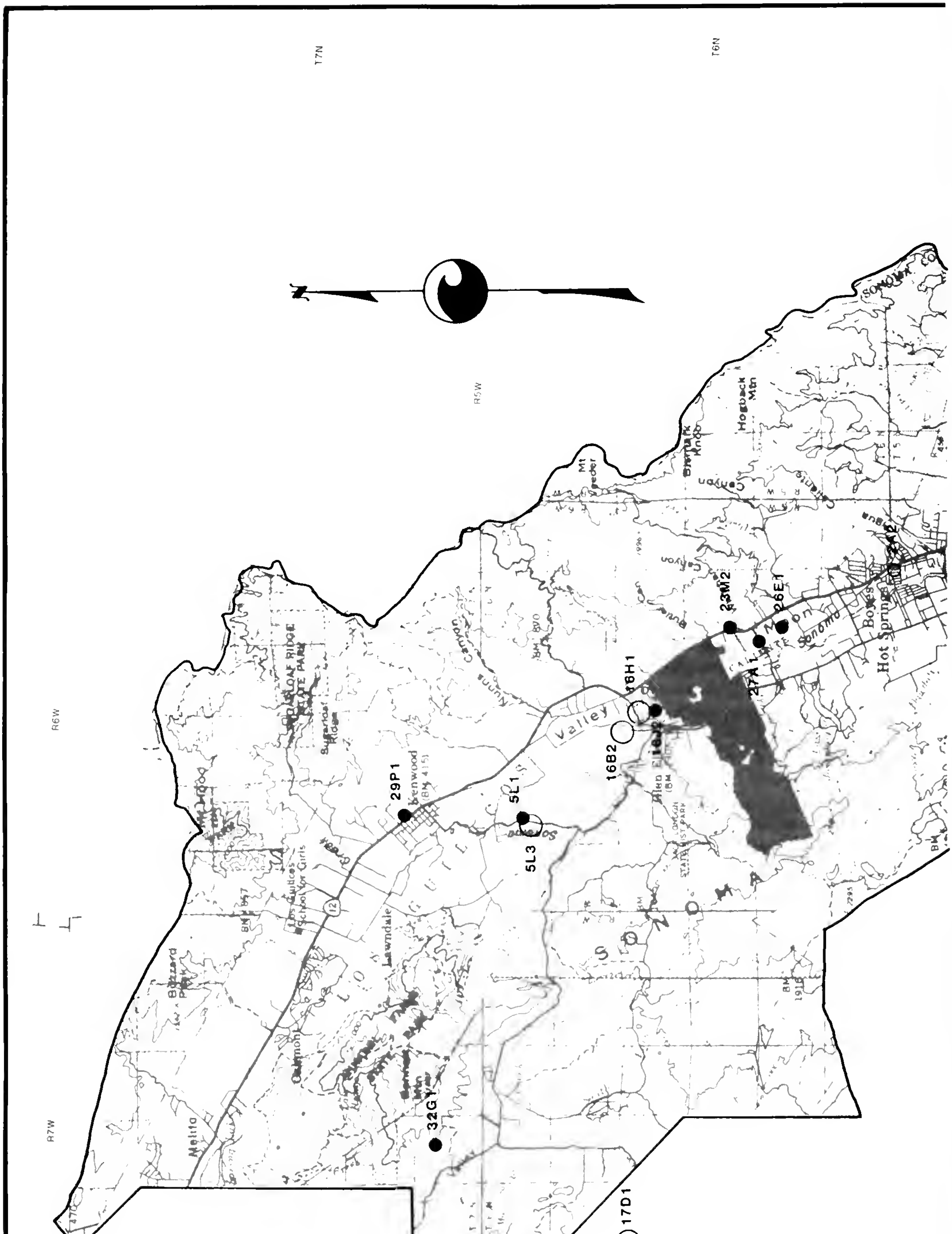
In the study area, hardness generally increases to the south and decreases with depth. The hardest water is generally found in areas affected by sea water intrusion. Hardness decreases with depth as the percentage of sodium in the ground water increases. This increase in sodium is due to cation exchange in clay, in which calcium and magnesium ions from ground water are affixed to clay particles and sodium ions are released.

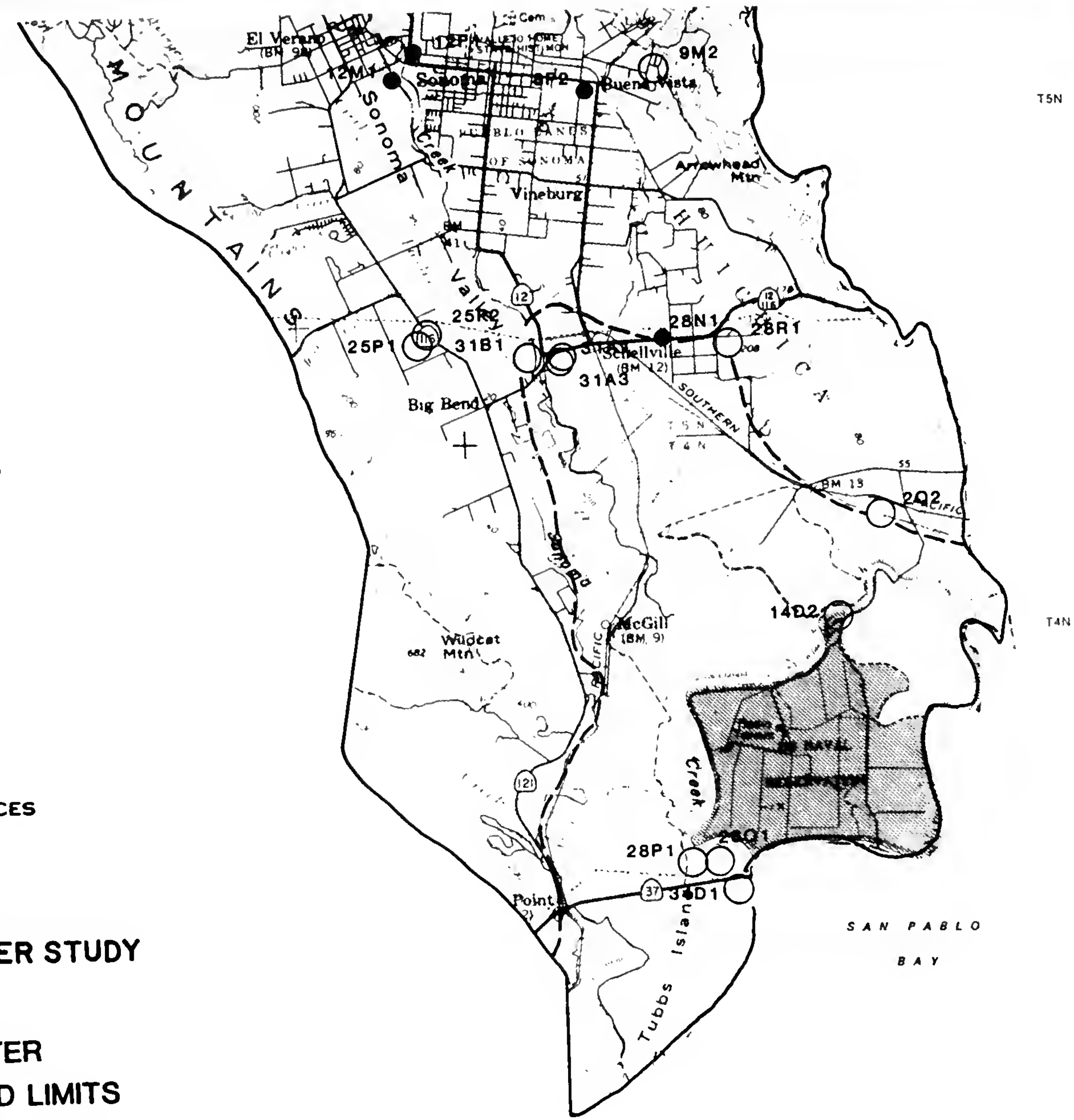
Table 6

BORON IN GROUND WATER IN
EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	(feet)	Date mo/yr	Boron mg/L*
4N/5W-28P1	--	(--)	8/67	2.6
-28Q1	--	(--)	8/54	2.2
-34D1	61	(200)	8/58	2.6
5N/5W-8P2	75	(245)	8/74	0.7
-9M2	78	(257)	1/51	1.0
-18D2	23	(75)	3/65	0.9
-20C1	38	(125)	9/51	0.56
-20R1	154	(504)	3/65	4.8
-28R1	85	(280)	7/71	1.1
-31A1	124	(408)	6/52	6.6
-31A3	17	(56)	4/54	1.6
5N/6W-2A2	107	(350)	9/59	0.94
-12F1	34	(113)	11/65	0.8
-13K1	--	(--)	9/51	4.4
-25P1	52	(171)	3/65, 8/67	1.4
-25P2	195	(640)	8/69	1.3
6N/6W-5L1	41	(133)	6/52	2.5
-5L3	2	(6)	5/52	3.5
-15J1	23	(75)	9/51	0.54
-16B2	64	(211)	9/51	7.7
-16H1	64	(210)	5/51	6.2
-16J2	--	(--)	10/49	7.7
-23M2	71	(233)	3/59	2.5
-26E1	93	(304)	3/59	3.2
-27A1	71	(233)	4/61	1.4
6N/7W-16D1	12	(38)	2/50	0.64
-17D1	--	(--)	1/57	1.2
-17E1	198	(650)	9/61	2.0

*All exceed recommended limit of Boron = 0.5 mg/L.


T7N
T6N
R5W
R6W
R7W
29P1
Kenwood
5L1
5L3
16B2
16H1
23M2
26E1
27A1
32G1
17D1
17E1
Valley
Sonoma
Boyes Hot Springs
Hogback Mtn
Lawndale
Melita
12



EXPLANATION

●	ASAR= 3.0-5.0	INCREASING PROBLEMS FOR AGRICULTURAL USE
○	ASAR> 5.0	SEVERE PROBLEMS FOR AGRICULTURAL USE

ASAR=ADJUSTED SODIUM ADSORPTION RATIO

FOR DATES OF ANALYSES, SEE TABLE 3

DASHED LINE INDICATES LANDWARD EXTENT OF SEA WATER INTRUSION (after Kunkel and Upson, 1960)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

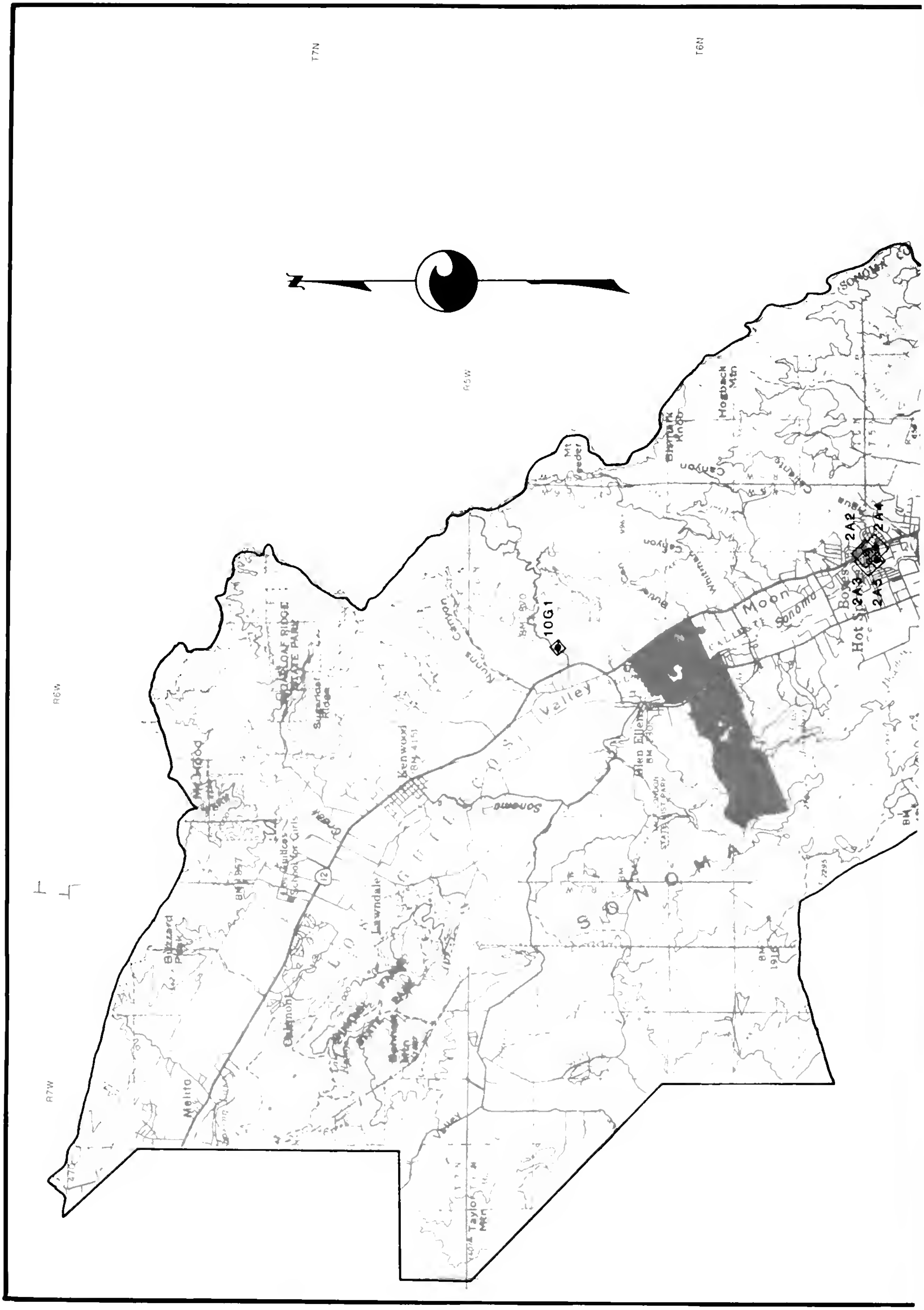
SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

SODIUM IN GROUND WATER
IN EXCESS OF RECOMMENDED LIMITS

SCALE

KILOMETRES: 1.5 0 1 2 3 4 5

MILES: 1 .5 0 1 2 3 4 5


T7N
T6N
R5W
R6W
R7W
10G1
2A2
2A3
2A4
2A5
Valley
Moon
Sonoma
Kenwood
Glen Ellen
Hogback Mtn
Lawndale
Melita
Taylor Mtn
12

EXPLANATION

◇ E.C.=160-3000 µS/cm — INCREASING PROBLEMS FOR AGRICULTURAL USE

◇ E.C.>3000 µS/cm — SEVERE PROBLEMS FOR AGRICULTURAL USE

E.C.=ELECTRICAL CONDUCTIVITY

CHLORIDE CONCENTRATION:

- ● 106-141 mg/L
- -●- 142-249 mg/L
- ○ 250-499 mg/L
- -○- > 600 mg/L

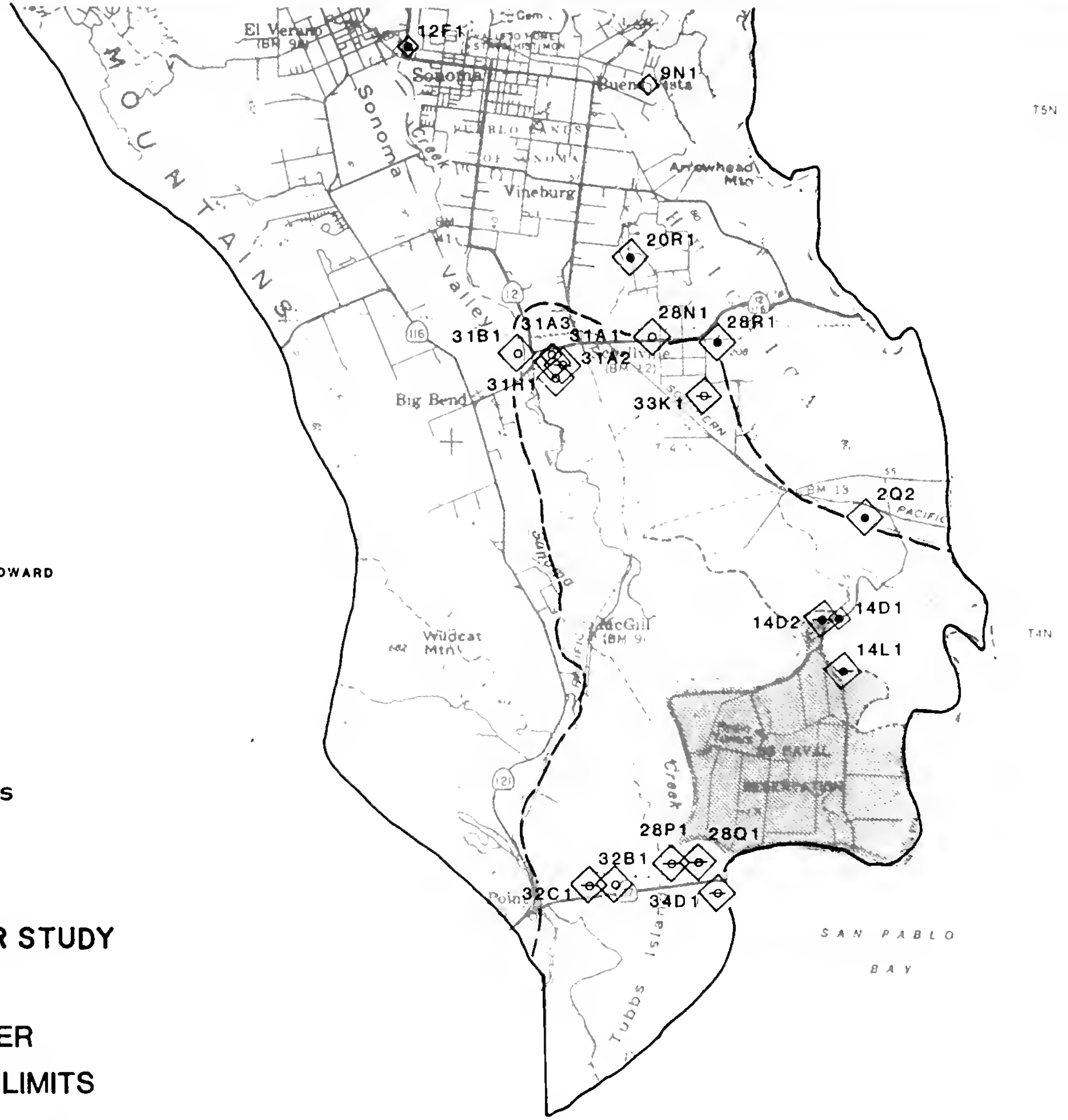
AGRICULTURAL USE:

106 mg/L	INCREASING PROBLEMS-FOLIAR ABSORPTION
142 mg/L	INCREASING PROBLEMS-ROOT ABSORPTION

DRINKING WATER:

250 mg/L	RECOMMENDED LIMIT
600 mg/L	MAXIMUM LIMIT

FOR DATES OF ANALYSES, SEE TABLE 4; DASHED LINE INDICATES LANDWARD EXTENT OF SEA WATER INTRUSION (after Kunkel and Upson, 1960)



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

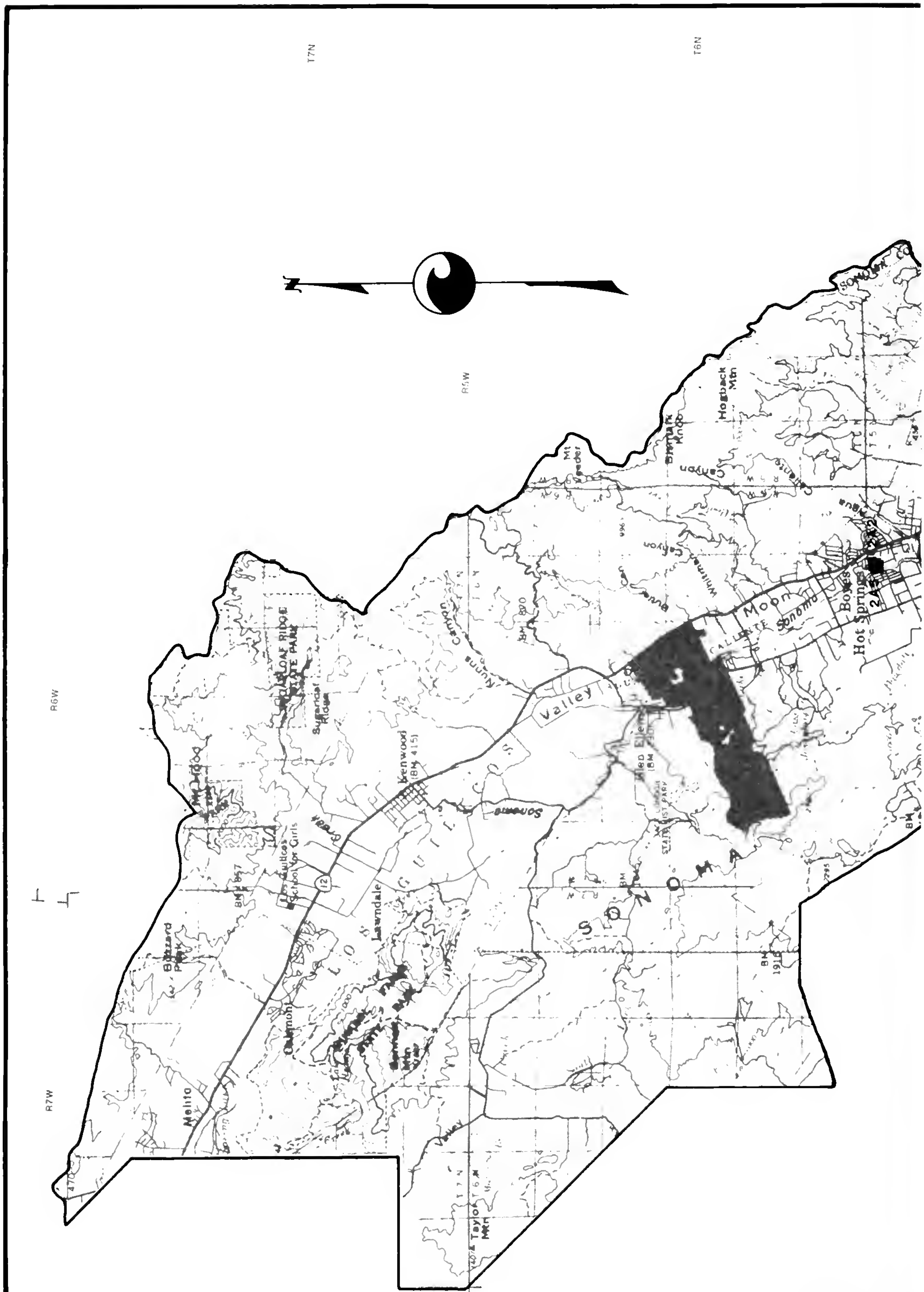
SALINITY IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS

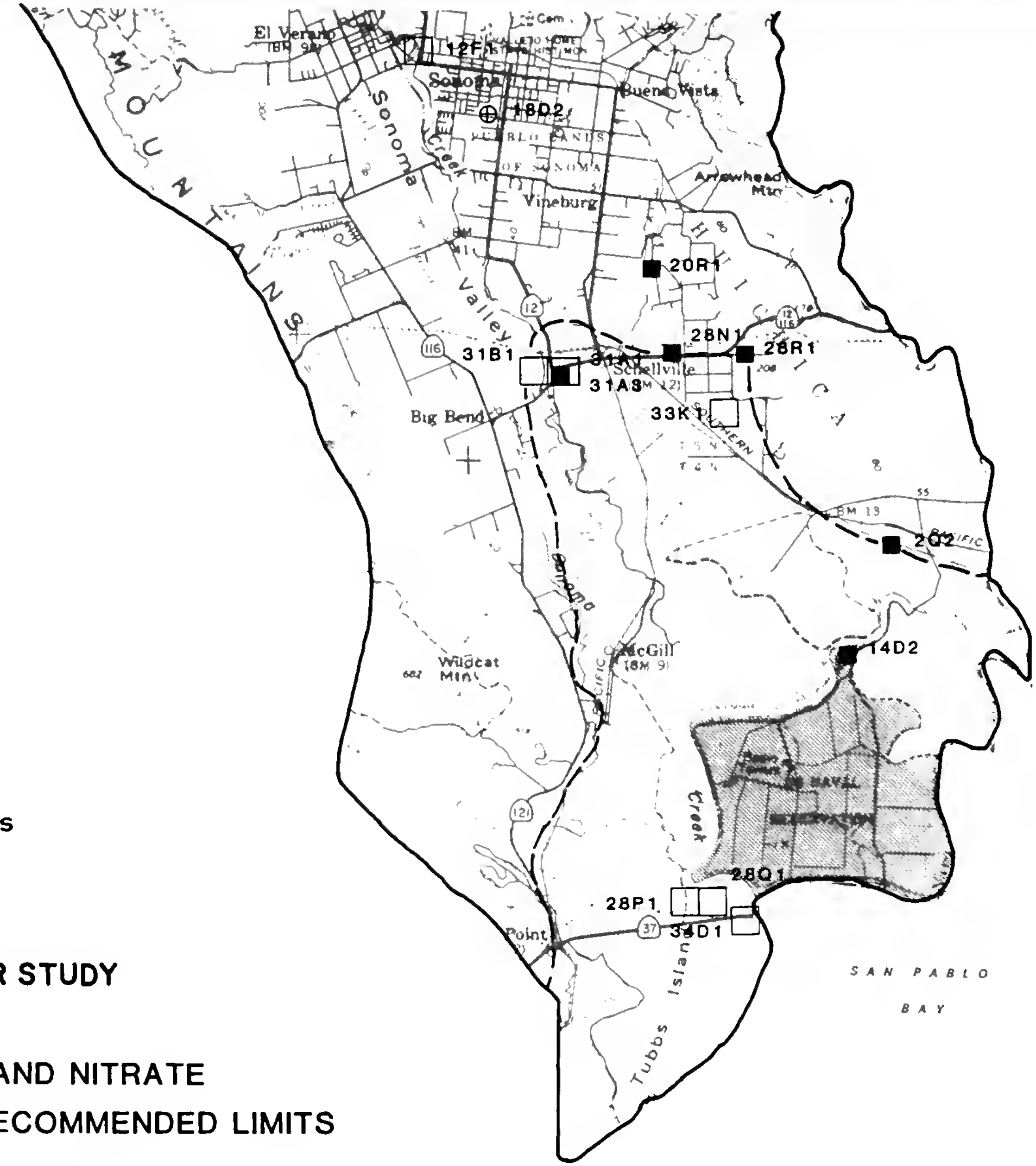
SCALE

1 .5 0 1 2 3 4 5 KILOMETRES

1 .5 0 1 2 3 4 5 MILES

FIGURE 13B


T7N
T6N
R5W
R6W
R7W
Kenwood (BM 415)
Valley
Moon
Sonoma
Lawndale
Oakmont
Melita
Hogback Mtn
Boyes Hot Springs
Sugarloaf Ridge
12



EXPLANATION

■ TDS = 500–1000 mg/L

□ TDS > 1000 mg/L

TDS = TOTAL DISSOLVED SOLIDS

DRINKING WATER:

500 mg/L	RECOMMENDED LIMIT
1000 mg/L	MAXIMUM LIMIT

⊕ NITRATE > 45 mg/L

FOR DATES OF ANALYSES, SEE TABLE 5

DASHED LINE INDICATES LANDWARD EXTENT OF SEA WATER INTRUSION (after Kunkel and Upson, 1960)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

TOTAL DISSOLVED SOLIDS AND NITRATE IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS

SCALE

1 .5 0 1 2 3 4 5 KILOMETRES

1 .5 0 1 2 3 4 5 MILES

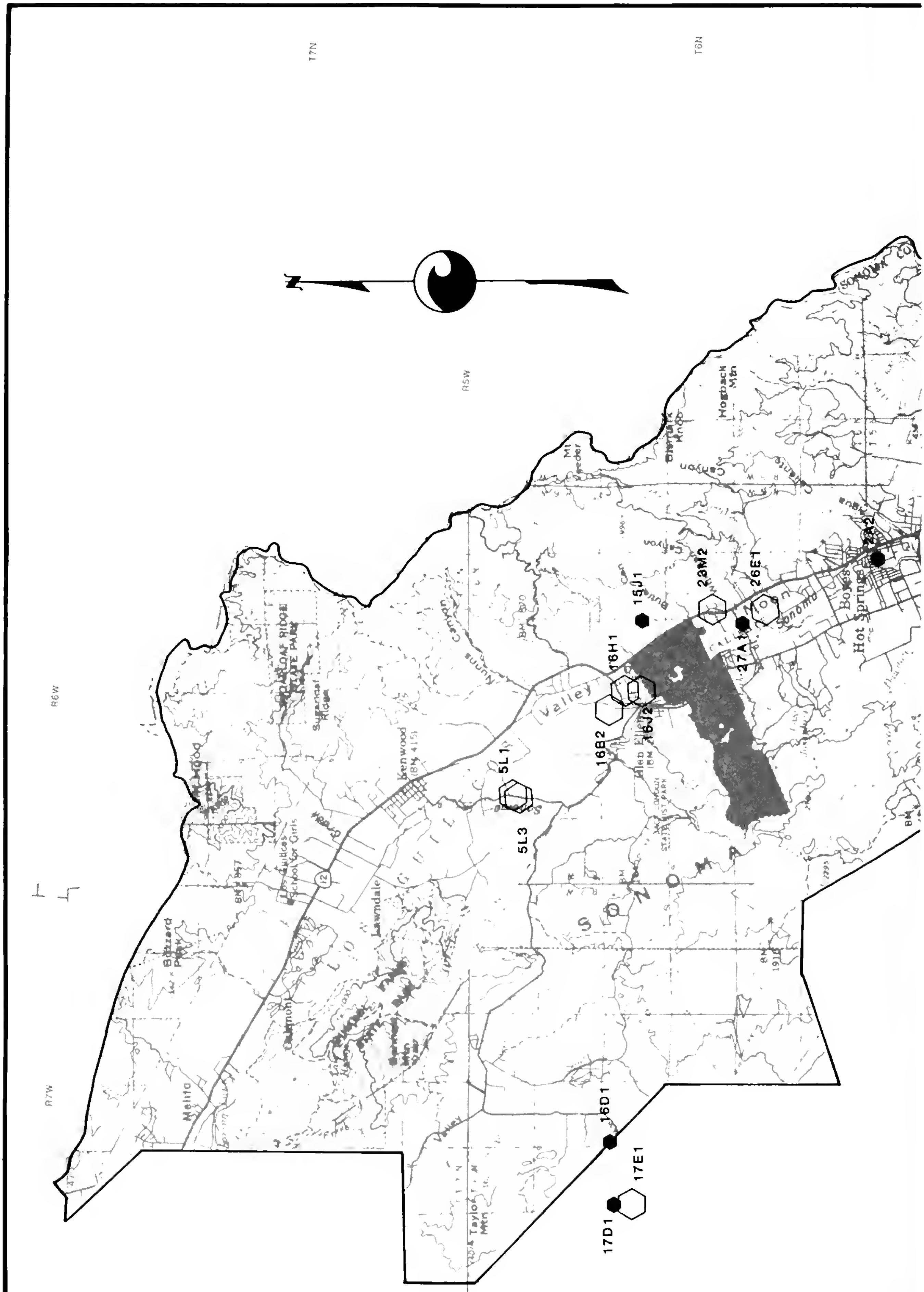
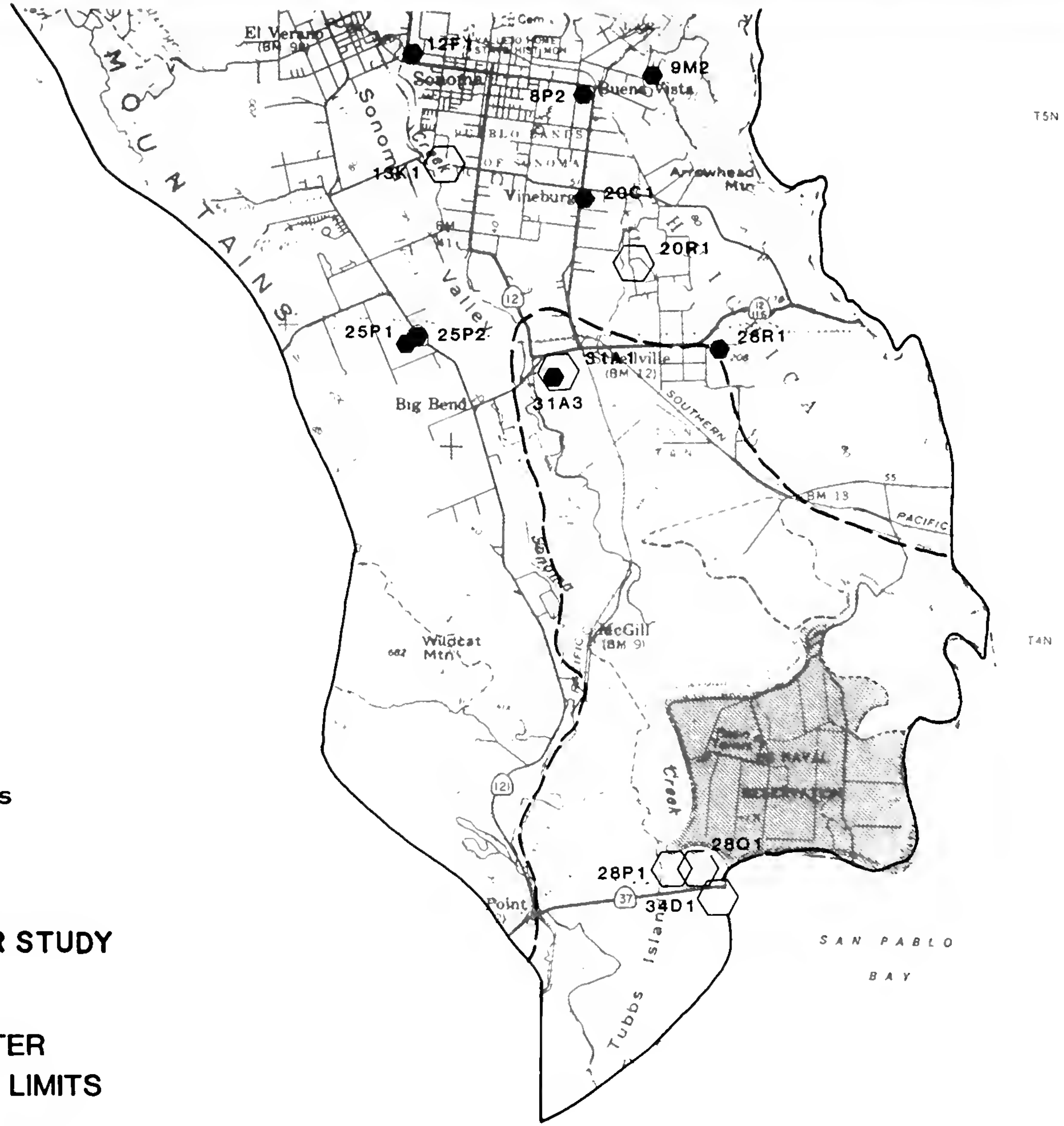

T7N
T6N
R5W
R6W
R7W
N
Kenwood
Lawndale
Melita
Hogback Mtn
Mt Veeder
Valley
Boyes
Hot Springs
Sonoma
SONOMA
SUGARLOAF RIDGE STATE PARK
5L1
5L3
16B2
16H1
16J2
15J1
23M2
26E1
27A1
16D1
17E1
17D1

FIGURE 13D



EXPLANATION

BORON

●	0.6-2.0 mg/L	INCREASING PROBLEMS FOR AGRICULTURAL USE
⬡	2.0 mg/L	SEVERE PROBLEMS FOR AGRICULTURAL USE

FOR DATES OF ANALYSES, SEE TABLE 8

DASHED LINE INDICATES LANDWARD EXTENT OF SEA WATER INTRUSION (after Kunkel and Upson, 1960)

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

BORON IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS

SCALE

.5 0 1 2 3 4 5 KILOMETRES

.5 0 1 2 3 4 5 MILES

In the Bennett Mountain area, water from alluvial fan deposits and the Sonoma Volcanics is soft. In the Glen Ellen area, shallow ground water is also soft. Two deeper wells that produce hard and moderately hard water tap the Sonoma Volcanics. In the Sonoma Valley study area, hardness increases to the south. The hardest water is 5 180 mg/L of calcium carbonate from well 5N/5W-33K1; the softest water is 12 mg/L from a deeper well, 5N/6W-25P2. Ground water from most alluvial fan deposits is moderately hard; ground water in areas intruded by sea water is mostly hard.

The greatest potential for a change in hardness is near areas affected by sea water intrusion. If ground water pumping produces a landward gradient, encouraging inland movement of sea water, hardness will increase as sea water moves into alluvial fan deposits.

Iron and Manganese

The presence of excessive iron and manganese in ground water is a common problem. Both of these constituents can impart a metallic taste to water or to food prepared with such water. The metallic impurities may also stain fixtures, fabrics, and utensils. The iron and manganese deposits build up in pressure tanks, water heaters, and pipes and reduce the available quantity and pressure of the water supply. The recommended limit is 0.3 mg/L for iron and 0.05 mg/L for manganese.

To obtain an accurate analysis of the amount of iron and manganese in a water sample, the sample must be acidified with nitric acid immediately after collection to stabilize the metallic constituents. If this is not done, some iron and manganese will precipitate out of solution. If plastic jugs are used for sampling, some iron and manganese will adhere to the plastic. Acidification of water samples has rarely been performed in the Sonoma Valley, making a general statement on the occurrence and movement of iron- and manganese-rich water impossible.

Water containing excessive iron and manganese has been produced from wells:

° Tapping alluvial fan deposits.
° Tapping the Glen Ellen Formation.
° Tapping the Sonoma Volcanics.

Table 7 lists wells in the Sonoma Valley known to produce water with iron or manganese in excess of recommended limits.

Sources of iron and manganese are varied. Iron is frequently present in the cementing material of sandstones and within shales. Iron is also found in the soils produced by weathering of these rocks. Iron may be added to ground water from contact with well casing, pump parts, pipes, storage tanks, and other iron objects. Iron can be derived from iron bacteria that grow in some well casings.

Manganese found in ground water is most frequently the result of solution of manganese from soils and sediments aided by anaerobic bacteria under reducing conditions.

In some parts of California, water rich in iron and manganese occurs near the bottom of various individual aquifers. Because iron and manganese ions are relatively heavy, they tend to settle in an aquifer until they are concentrated just above a clay bed. Water drawn from a well perforated near the bottom of an aquifer would therefore tend to have a greater concentration of iron and manganese. Sufficient data are not available to evaluate this phenomenon in the Sonoma Valley.

Well Owner Questionnaire Results

To determine well owners' opinions of their ground water quality, the Sonoma County Water Agency mailed questionnaires in 1977 to all rural property owners in Sonoma County who did not receive water from municipal water systems. The questionnaires requested information on ground water taste, odor, and color. The

responses were grouped according to assessor's parcel books (Figure 14). Within each parcel book area, responses were separated according to well depth:

° Shallow wells, 0-46 m (0-150 ft) deep.

° Intermediate wells, 46-107 m (151-350 ft) deep.

° Deep wells, greater than 107 m (350 ft) deep.

Within each depth range, the number of wells with each of the following problems was tabulated:

° Taste
° Odor
° Color
° Other (problem)
° None (no problem)

Since a single well could have more than one problem, two other tabulations were added: (1) taste, odor, or color; and (2) taste, odor, color, or other. The responses to the questionnaires are tabulated in Table 8.

The most common complaint was color. Some causes of colored water are excessive iron and manganese and the pumping of sand. Pumping of sand is much more common in the Petaluma Valley and Santa Rosa Plain than in the Sonoma Valley study area. Unpleasant taste can be caused by excessive hardness, salinity, sodium, iron and manganese, and sulfides. Sulfides are generally volcanic in origin. Unpleasant odor can be caused by excessive iron and manganese and hydrogen sulfide.

Table 7

IRON AND MANGANESE IN GROUND WATER
IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	Depth (feet)	Date mo/yr	Iron (total) mg/L	Manganese mg/L
4N/5W-14D2	494	(1620)	8/54	0.8*	0.1*
			10/60	0.14	0.16*
-28P1	--	(--)	4/60	2.6*	--
-28Q1	--	(--)	8/54	0.02	0.1*
-34D1	61	(200)	3/59	0.4*	--
5N/5W-20R1	154	(504)	4/61	0	0.06*
-33K1	58	(190)	3/59	25	--
5N/6W-2A2	107	(350)	--	0.93*	--
-12F1	34	(113)	4/60	7.8*	--
			4/61	0.0	0.06*

Well Number	Depth metres	Depth (feet)	Date mo/yr	Iron (total) mg/L	Manganese mg/L
6N/6W-5L1	41	(133)	9/51	0.18	0.14*
-10M2	68	(224)	6/75	0.85*	0.13*
-16	44	(145)	2/62	1.8*	0.26*
-23M2	71	(233)	4/60	0.72*	--
			4/61	0.05	0.3*
-26E1	93	(304)	4/60	0.53*	--
-27A1	71	(233)	4/61	0.02	0.19*
-35G2	40	(130)	8/58	0.5*	--
6N/7W-5A1	37	(120)	4/60	5.0*	0.48*
-17E1	198	(650)	9/61	0.79*	0.0
7N/6W-29P1	34	(112)	6/75	4.0*	0.55*
7N/7W-15C1	121	(397)	9/61	0.74*	0.53*

*Concentration is above recommended limits of 0.3 mg/L iron or 0.05 mg/L manganese.

FIGURE 14

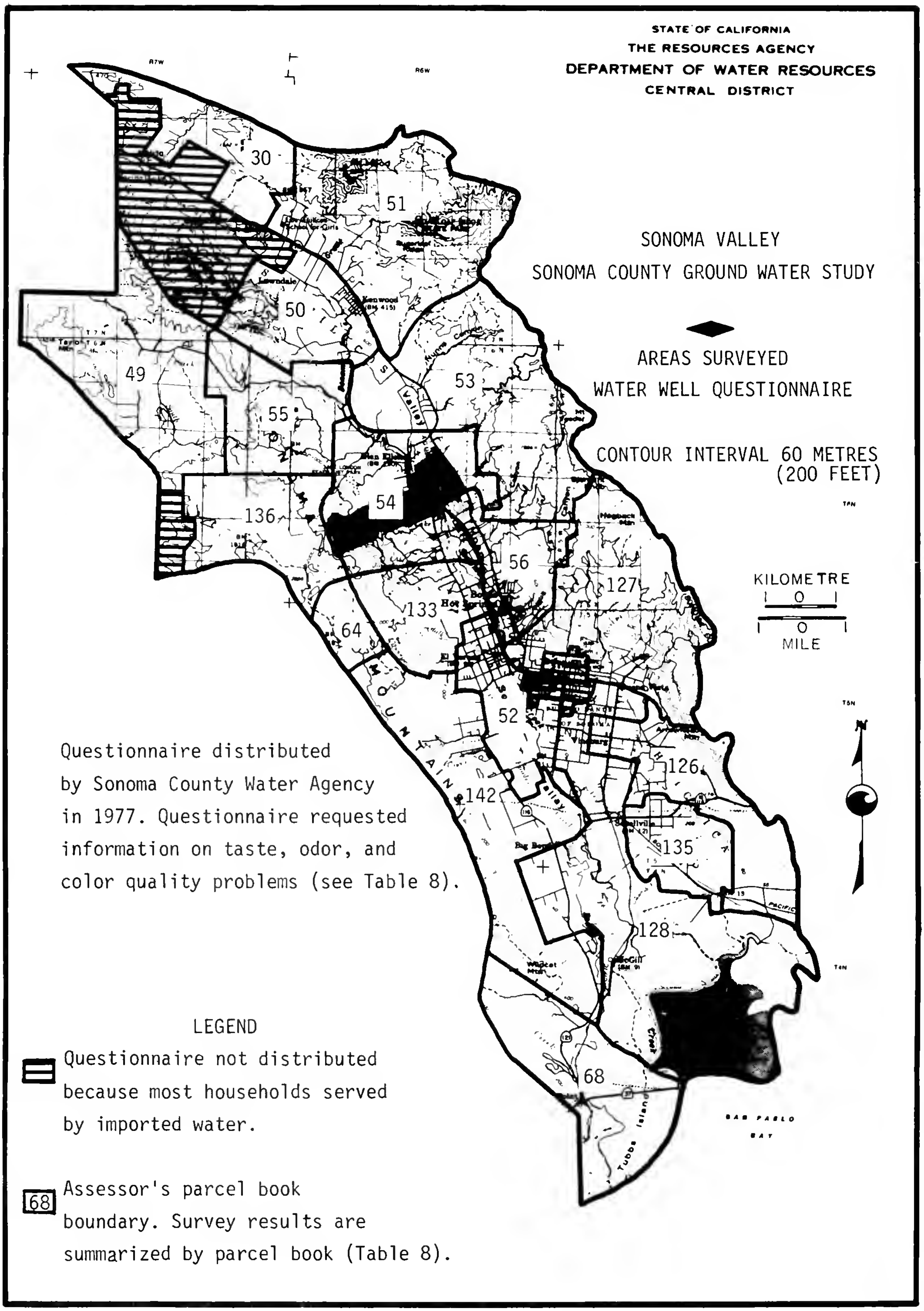

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY
AREAS SURVEYED
WATER WELL QUESTIONNAIRE
CONTOUR INTERVAL 60 METRES
(200 FEET)
KILOMETRE
0
MILE
0
30
51
50
49
53
55
54
136
56
127
133
64
52
126
142
135
128
68
Questionnaire distributed
by Sonoma County Water Agency
in 1977. Questionnaire requested
information on taste, odor, and
color quality problems (see Table 8).
LEGEND
Questionnaire not distributed
because most households served
by imported water.
68
Assessor's parcel book
boundary. Survey results are
summarized by parcel book (Table 8).

TABLE 8 1/

WATER WELL QUESTIONNAIRE RESPONSES
1977 DATA

ASSESSORS PARCEL BOOK NO. 30 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	3	1	0	2	6
ODOR	4	2	0	1	7
COLOR	5	5	6	1	17
OTHER	10	8	2	6	26
NONE	49	32	3	43	127
TASTE, ODOR OR COLOR	5	6	6	3	20
TASTE, ODOR, COLOR OR OTHER	13	13	7	9	42
NUMBER OF WELLS IN SURVEY	62	45	10	52	169
% WELLS WITH T,O,C QUALITY PROBLEM	8.1%	13.3%	60.0%	5.8%	11.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	21.0%	28.9%	70.0%	17.3%	24.9%

ASSESSORS PARCEL BOOK NO. 49 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	17	15	3	7	42
ODOR	15	16	3	6	40
COLOR	21	17	4	6	48
OTHER	12	7	4	3	26
NONE	16	12	9	10	47
TASTE, ODOR OR COLOR	25	23	6	9	63
TASTE, ODOR, COLOR OR OTHER	32	27	9	11	79
NUMBER OF WELLS IN SURVEY	48	39	18	21	126
% WELLS WITH T,O,C QUALITY PROBLEM	52.1%	59.0%	33.3%	42.9%	50.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	66.7%	69.2%	50.0%	52.4%	62.7%

ASSESSORS PARCEL BOOK NO. 50 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	8	5	1	2	16
ODOR	6	2	0	1	9
COLOR	9	5	0	5	19
OTHER	6	5	1	1	13
NONE	30	13	3	19	65
TASTE, ODOR OR COLOR	13	6	1	6	26
TASTE, ODOR, COLOR OR OTHER	17	11	2	7	37
NUMBER OF WELLS IN SURVEY	47	24	5	26	102
% WELLS WITH T,O,C QUALITY PROBLEM	27.7%	25.0%	20.0%	23.1%	25.5%
% WELLS WITH T,O,C,X QUALITY PROBLEM	36.2%	45.8%	40.0%	26.9%	36.3%

ASSESSORS PARCEL BOOK NO. 51 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	4	2	0	0	6
ODOR	3	1	0	0	4
COLOR	5	2	0	0	7
OTHER	1	3	3	0	7
NONE	11	10	0	10	31
TASTE, ODOR OR COLOR	7	3	0	0	10
TASTE, ODOR, COLOR OR OTHER	8	6	3	0	17
NUMBER OF WELLS IN SURVEY	19	16	3	10	48
% WELLS WITH T,O,C QUALITY PROBLEM	36.8%	18.8%	.0%	.0%	20.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	42.1%	37.5%	100.0%	.0%	35.4%

ASSESSORS PARCEL BOOK NO. 52 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	3	1	0	1	5
ODOR	4	2	0	2	8
COLOR	5	2	0	1	8
OTHER	3	0	0	1	4
NONE	38	6	0	4	48
TASTE, ODOR OR COLOR	8	2	0	2	12
TASTE, ODOR, COLOR OR OTHER	11	2	0	3	16
NUMBER OF WELLS IN SURVEY	49	8	0	7	64
% WELLS WITH T,O,C QUALITY PROBLEM	16.3%	25.0%	N/A	28.6%	18.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	22.4%	25.0%	N/A	42.9%	25.0%

ASSESSORS PARCEL BOOK NO. 53 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	9	10	0	2	21
ODOR	8	10	0	1	19
COLOR	8	13	0	2	23
OTHER	5	4	0	1	10
NONE	16	12	2	8	38
TASTE, ODOR OR COLOR	13	16	0	4	33
TASTE, ODOR, COLOR OR OTHER	15	20	0	5	40
NUMBER OF WELLS IN SURVEY	31	32	2	13	78
% WELLS WITH T,O,C QUALITY PROBLEM	41.9%	50.0%	.0%	30.8%	42.3%
% WELLS WITH T,O,C,X QUALITY PROBLEM	48.4%	62.5%	.0%	38.5%	51.3%

1/ FOR LOCATION OF ASSESSOR'S PARCEL BOOKS SEE FIGURE 14

TABLE 8 (continued)

ASSESSORS PARCEL BOOK NO. 54 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	4	1	1	0	6
ODOR	3	1	1	0	5
COLOR	3	1	1	1	6
OTHER	1	0	1	1	3
NONE	1	5	1	3	10
TASTE, ODOR OR COLOR	4	1	1	1	7
TASTE, ODOR, COLOR OR OTHER	4	1	2	2	9
NUMBER OF WELLS IN SURVEY	5	6	3	5	19
% WELLS WITH T,O,C QUALITY PROBLEM	80.0%	16.7%	33.3%	20.0%	36.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	80.0%	16.7%	66.7%	40.0%	47.4%

ASSESSORS PARCEL BOOK NO. 55 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	3	1	1	1	6
ODOR	2	2	1	1	6
COLOR	6	1	2	1	10
OTHER	2	0	0	0	2
NONE	3	10	7	3	23
TASTE, ODOR OR COLOR	7	2	2	1	12
TASTE, ODOR, COLOR OR OTHER	9	2	2	1	14
NUMBER OF WELLS IN SURVEY	12	12	9	4	37
% WELLS WITH T,O,C QUALITY PROBLEM	58.3%	16.7%	22.2%	25.0%	32.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	75.0%	16.7%	22.2%	25.0%	37.8%

ASSESSORS PARCEL BOOK NO. 56 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	0	0	3	4
ODOR	2	0	0	2	4
COLOR	3	0	0	2	5
OTHER	4	1	0	0	5
NONE	16	17	1	7	41
TASTE, ODOR OR COLOR	5	0	0	4	9
TASTE, ODOR, COLOR OR OTHER	9	1	0	4	14
NUMBER OF WELLS IN SURVEY	25	18	1	11	55
% WELLS WITH T,O,C QUALITY PROBLEM	20.0%	.0%	.0%	36.4%	16.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	36.0%	5.6%	.0%	36.4%	25.5%

ASSESSORS PARCEL BOOK NO. 64 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	0	0	1	1
ODOR	0	0	0	1	1
COLOR	1	0	0	1	2
OTHER	0	0	0	0	0
NONE	0	1	0	0	1
TASTE, ODOR OR COLOR	1	0	0	1	2
TASTE, ODOR, COLOR OR OTHER	1	0	0	1	2
NUMBER OF WELLS IN SURVEY	1	1	0	1	3
% WELLS WITH T,O,C QUALITY PROBLEM	100.0%	.0%	N/A	100.0%	66.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	100.0%	.0%	N/A	100.0%	66.7%

ASSESSORS PARCEL BOOK NO. 68 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	5	2	0	2	9
ODOR	5	0	0	0	5
COLOR	0	2	0	0	2
OTHER	1	0	1	1	3
NONE	10	8	2	7	27
TASTE, ODOR OR COLOR	6	2	0	2	10
TASTE, ODOR, COLOR OR OTHER	6	2	1	3	12
NUMBER OF WELLS IN SURVEY	16	10	3	10	39
% WELLS WITH T,O,C QUALITY PROBLEM	37.5%	20.0%	.0%	20.0%	25.6%
% WELLS WITH T,O,C,X QUALITY PROBLEM	37.5%	20.0%	33.3%	30.0%	30.8%

ASSESSORS PARCEL BOOK NO. 126 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	13	9	6	3	31
ODOR	8	12	4	2	26
COLOR	7	6	5	3	21
OTHER	5	7	2	0	14
NONE	19	11	4	6	40
TASTE, ODOR OR COLOR	19	14	6	6	45
TASTE, ODOR, COLOR OR OTHER	23	17	7	6	53
NUMBER OF WELLS IN SURVEY	42	28	11	12	93
% WELLS WITH T,O,C QUALITY PROBLEM	45.2%	50.0%	54.5%	50.0%	48.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	54.8%	60.7%	63.6%	50.0%	57.0%

TABLE 8 (continued)

ASSESSORS PARCEL BOOK NO. 127 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	17	13	4	9	43
ODOR	19	15	3	11	47
COLOR	25	17	4	9	55
OTHER	9	5	2	1	17
NONE	29	9	8	18	64
TASTE, ODOR OR COLOR	27	21	6	13	67
TASTE, ODOR, COLOR OR OTHER	32	24	6	13	75
NUMBER OF WELLS IN SURVEY	61	33	14	31	139
% WELLS WITH T,O,C QUALITY PROBLEM	44.3%	63.6%	42.9%	41.9%	48.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	52.5%	72.7%	42.9%	41.9%	54.0%

ASSESSORS PARCEL BOOK NO. 128 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	15	6	2	5	28
ODOR	18	4	2	5	29
COLOR	21	1	3	3	28
OTHER	12	0	0	1	13
NONE	141	14	1	45	201
TASTE, ODOR OR COLOR	28	6	3	6	43
TASTE, ODOR, COLOR OR OTHER	38	6	3	6	53
NUMBER OF WELLS IN SURVEY	179	20	4	51	254
% WELLS WITH T,O,C QUALITY PROBLEM	15.6%	30.0%	75.0%	11.8%	16.9%
% WELLS WITH T,O,C,X QUALITY PROBLEM	21.2%	30.0%	75.0%	11.8%	20.9%

ASSESSORS PARCEL BOOK NO. 133 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	3	1	2	7
ODOR	1	2	1	1	5
COLOR	2	4	1	2	9
OTHER	3	3	0	1	7
NONE	11	9	1	10	31
TASTE, ODOR OR COLOR	3	4	1	4	12
TASTE, ODOR, COLOR OR OTHER	5	6	1	5	17
NUMBER OF WELLS IN SURVEY	16	15	2	15	48
% WELLS WITH T,O,C QUALITY PROBLEM	18.8%	26.7%	50.0%	26.7%	25.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	31.3%	40.0%	50.0%	33.3%	35.4%

ASSESSORS PARCEL BOOK NO. 135 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	2	1	0	4
ODOR	1	1	1	0	3
COLOR	1	1	1	0	3
OTHER	0	1	1	0	2
NONE	11	4	1	0	16
TASTE, ODOR OR COLOR	1	2	2	0	5
TASTE, ODOR, COLOR OR OTHER	1	3	2	0	6
NUMBER OF WELLS IN SURVEY	12	7	3	0	22
% WELLS WITH T,O,C QUALITY PROBLEM	8.3%	28.6%	66.7%	N/A	22.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	8.3%	42.9%	66.7%	N/A	27.3%

ASSESSORS PARCEL BOOK NO. 136 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	2	2	0	0	4
ODOR	3	1	0	0	4
COLOR	3	1	0	0	4
OTHER	4	3	0	0	7
NONE	10	7	2	3	22
TASTE, ODOR OR COLOR	3	2	0	0	5
TASTE, ODOR, COLOR OR OTHER	6	4	0	0	10
NUMBER OF WELLS IN SURVEY	16	11	2	3	32
% WELLS WITH T,O,C QUALITY PROBLEM	18.8%	18.2%	.0%	.0%	15.6%
% WELLS WITH T,O,C,X QUALITY PROBLEM	37.5%	36.4%	.0%	.0%	31.3%

ASSESSORS PARCEL BOOK NO. 142 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM				
	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	5	2	0	0	7
ODOR	2	2	0	0	4
COLOR	4	2	0	0	6
OTHER	3	2	0	2	7
NONE	34	11	0	10	55
TASTE, ODOR OR COLOR	6	3	0	0	9
TASTE, ODOR, COLOR OR OTHER	9	5	0	2	16
NUMBER OF WELLS IN SURVEY	43	16	0	12	71
% WELLS WITH T,O,C QUALITY PROBLEM	14.0%	18.8%	N/A	.0%	12.7%
% WELLS WITH T,O,C,X QUALITY PROBLEM	20.9%	31.3%	N/A	16.7%	22.5%

Chapter 7. PLANNING FOR GROUND WATER MANAGEMENT

This chapter discusses alternative plans for ground water management in Sonoma Valley. The concept of ground water basin management includes planned use of the ground water basin yield, storage space, transmission capability, and water in storage. It includes (1) protection of natural recharge and use of artificial recharge; (2) planned variation in amount and location of pumping over time; (3) use of ground water storage conjunctively with surface water from local and imported sources; and (4) protection and planned maintenance of ground water quality (Peters, 1980).

Use of ground water storage conjunctively with surface water is practiced in some areas in California where extensive use of ground water has partially dewatered a basin, creating additional space to store water underground. The Santa Clara Basin in Northern California, for example, is operated much like a bank account. During wet periods, excess surface water is "deposited" -- artificially recharged to fill the additional underground storage space. During dry periods, when there is less surface water, ground water is "withdrawn" -- pumped to supplement available surface water supplies.

Natural topographic constraints prevent the Bennett Mountain area and Sonoma Valley ground water basins from filling more than the present 79 percent indicated by the computer program TRANSCAP (Chapter 4). If the basins are more than the 79 percent full indicated by TRANSCAP, the additional ground water begins to "leak out" along roadcuts and into streams. This spillage of excess water that cannot be stored underground is a form of rejected recharge. The Bennett Mountain area and Sonoma Valley basins are therefore, in effect, completely filled at the present time. For a program similar to that in the Santa Clara Basin to be practical, the volume of ground water in storage would have to be reduced below the present 79 percent to create storage space for water presently being rejected by the basin.

A ground water management program must be carefully examined from an economic viewpoint to determine costs versus the benefits of increased recharge. Lowered ground water tables require increased pumping lifts and consequently increase energy costs. Lowered water tables may also necessitate deepening of shallow wells and may result in costly litigation by existing shallow-well owners against new and high-use well owners.

More ground water could be stored in the Bennett Mountain area and the northern Sonoma Valley if ground water levels were drawn down further, making more storage space available. During the 1976-1977 drought, ground water levels dropped an average of 2 m (7 ft) below normal fall lows, yet returned to normal spring high levels after only one winter's rains. The maximum that basin water levels could be drawn down and yet recover in one winter is not known.

Certain special characteristics control the way that the Bennett Mountain area and Sonoma Valley basins can be operated. These special characteristics are:

- Continuing sea water intrusion into the southern Sonoma Valley study area and resulting poor quality water.
- The relatively thin alluvial fan deposits that fill each basin.
- The inconsistent water-yielding characteristics of the Sonoma Volcanics which frequently underlie and surround the alluvial fan deposits, Glen Ellen Formation, and Huichica Formation.

The possibility of increased sea water intrusion seriously restricts the amount that ground water pumpage can be increased in the southern Sonoma Valley study area.

The alluvial fan deposits are the only water-yielding unit in the basin for which hydrologic characteristics can be quantified. The Glen Ellen, Huichica, and Petaluma Formations are not significant producers of ground water.

The hundreds of metres of Sonoma Volcanics which frequently underlie the fan deposits and compose the mountainous areas contain ground water, but are unpredictable in their water-yielding characteristics. If ground water pumping from alluvial fan deposits were greatly increased, poor quality water might move from water-yielding units in the Sonoma Volcanics into the fan deposits; there is no way at present to predict the long-term impact of increased pumpage. Likewise, there is no way at present to estimate the volume of ground water moving from the Sonoma Volcanics to recharge fan deposits.

The amount of ground water that can be used in the study area varies depending on the location. In the main valley of the Bennett Mountain area, present levels of use can be continued indefinitely, and could be increased. Data from the ground water level monitoring network implemented by the Department of Water Resources and the Sonoma County Water Agency should be examined periodically for large declines in the ground water level.

In the Glen Ellen area, ground water is of limited supply and poor quality. The potential for expanded use of ground water from deposits other than the Sonoma Volcanics is low; the potential for expanded use from Sonoma Volcanics is unknown.

In the Sonoma Valley study area, ground water use in the northern half could possibly be expanded. Pumping should not be increased in the southern half near the area presently affected by sea water intrusion. If future ground water quality sampling indicates increasing intrusion, a detailed geohydrologic study should be conducted to determine the best mitigating measure. A variety of alternatives should be considered. Pumping could be further reduced in the southern half of the valley. Extensive use of surface water in southern valley communities has already reduced the potential for increased sea water intrusion. If reduced pumpage is not sufficient or feasible, artificial recharge may be necessary to stop further sea water intrusion. Recharge, probably by injecting water via specially designed wells, could be done near the affected area; the recharged water will flush the poorer quality water back toward San Pablo Bay. The water used for recharge can be treated waste water if the waste water is of better quality than the intrusion-affected water it flushes out.

Chapter 8. PROPOSED GROUND WATER DATA COLLECTION PROGRAMS

Additional data on ground water are needed to refine estimates of the total water in storage and to define more precisely the hydrology of the Bennett Mountain area and Sonoma Valley ground water basins so that the ground water resources can be managed prudently.

Determination of Ground Water Levels

To accurately evaluate the ground water potential of an area, a wide areal distribution of ground water level data gathered over a long period of time is necessary. This information can be used to determine the overall condition of the basin and to define areas of intense, increasing, or decreasing ground water pumpage. Ground water level data can also be used to evaluate the effects of geologic structures, such as faults and geologic formations, on the movement and occurrence of ground water. Ground water level maps constructed from these data permit a more accurate evaluation of ground water resources.

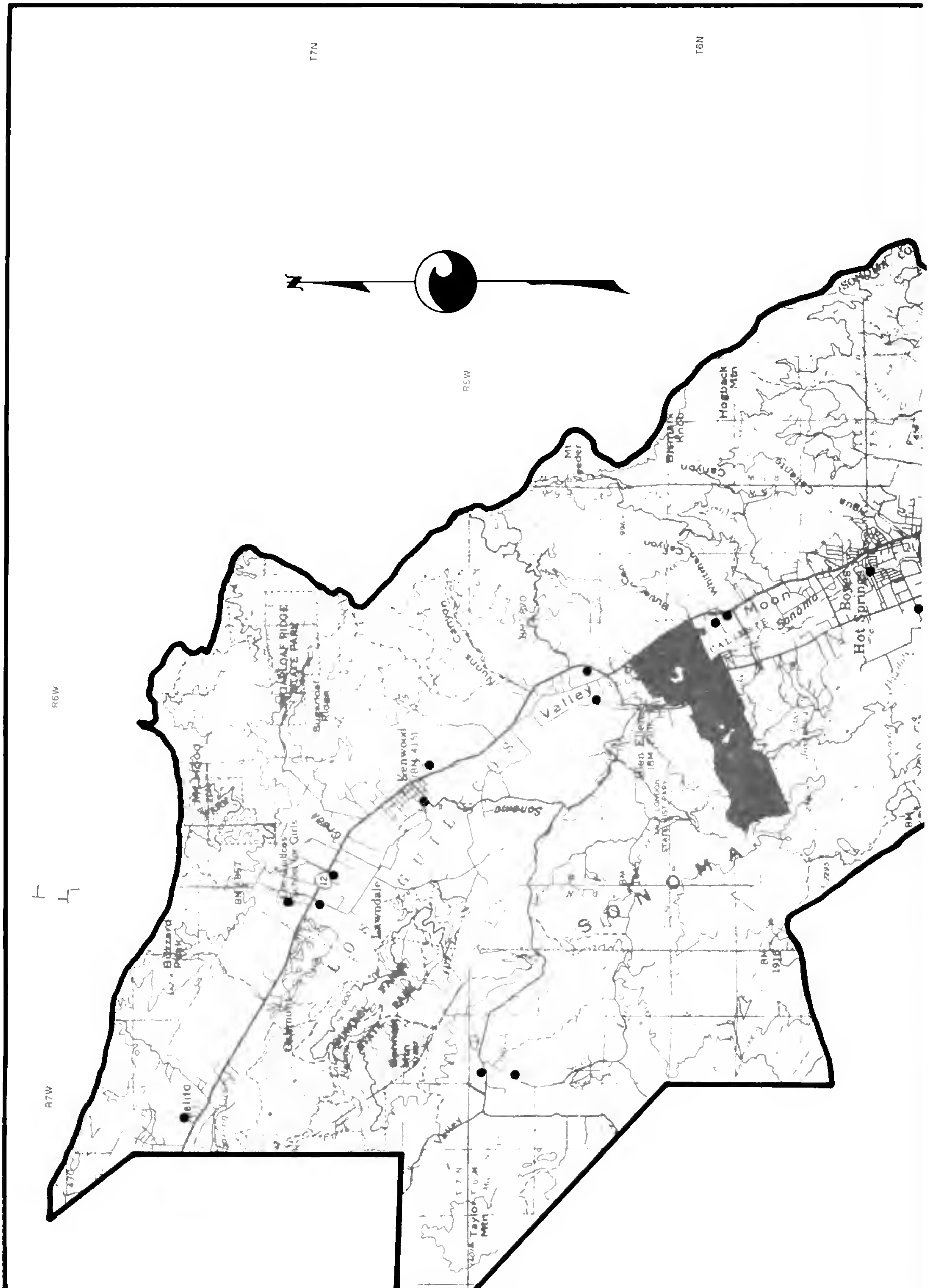
At present, 13 wells in the Bennett Mountain area and Sonoma Valley study area are being monitored by DWR. A new network has been implemented by SCWA and is being monitored by DWR. The network consists of 12 of the presently monitored wells and existing wells at 19 additional locations (Figure 15). The 19 additional locations were selected on the basis of geology, hydrology, existence of a well at that location, and information on the construction of the well. The additional wells have construction data that are vital in determining the zone from which ground water is being extracted; presently monitored wells lacking these data have been dropped from the new network.

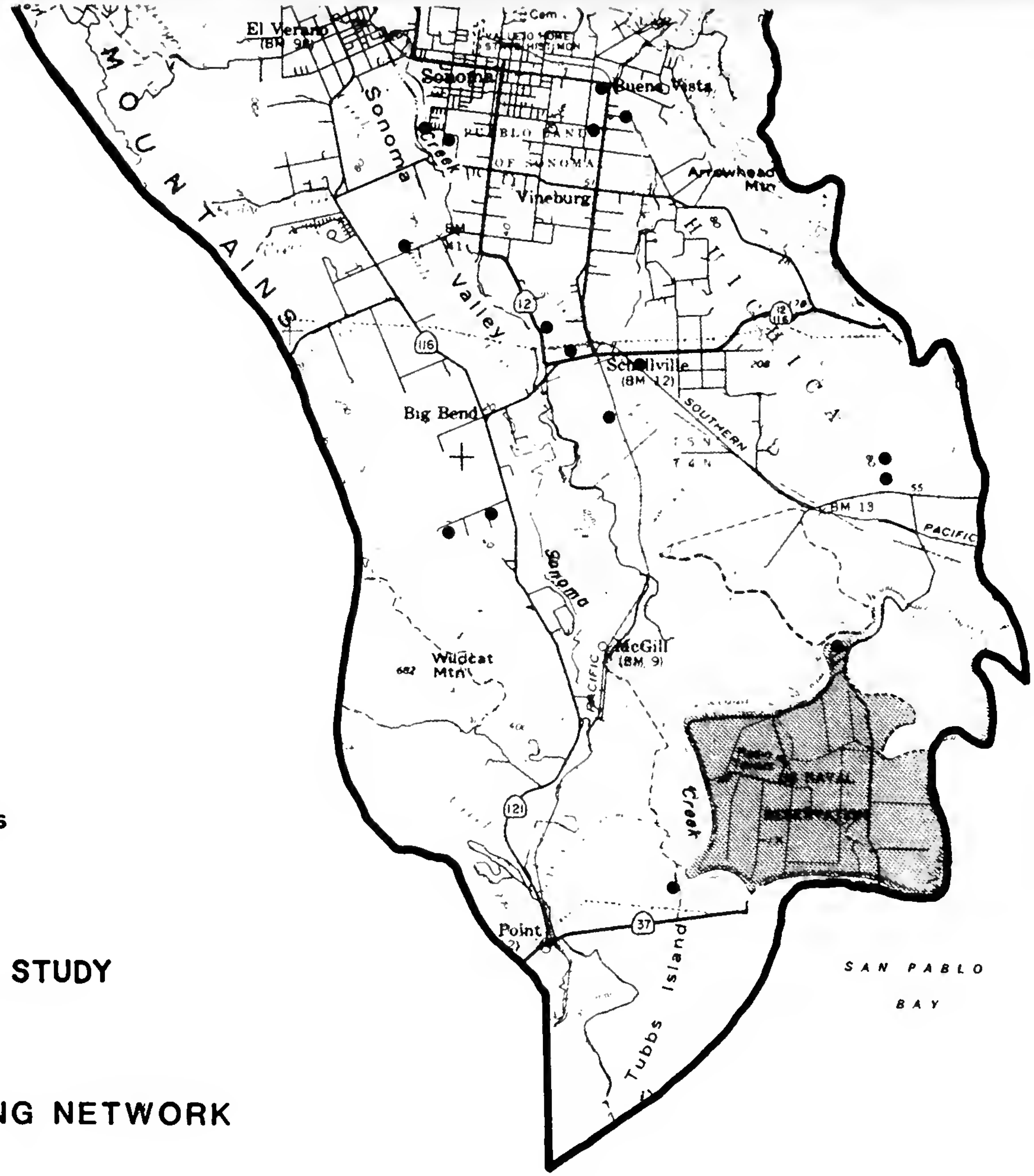
Wells at the additional locations tap a single aquifer or zone, and therefore represent the water level of this ground water body alone. A few "deep composite" wells have been selected for areas where no other wells are available; these wells have known construction data and tap ground water from several aquifers or zones. Water levels in deep composite wells can be correlated with water levels in other wells of similar depth and construction (gravel packed or multiple perforations) to determine the effects of faults and other barriers on the movement of ground water.

After several years of measurement, data from the new network should be analyzed to better define basin hydrology, including the role of faults in ground water movement and the extent of aquifer continuity. After sufficient ground water level data have been collected to verify estimates of total ground water in storage and change in storage, the monitoring network should be reevaluated. Those wells whose data are no longer necessary should be dropped.

Determination of Annual Amount of Ground Water Recharge

The amount of water that can be extracted annually from a ground water basin without causing adverse effects is the sustained yield of that basin; it generally equals the average volume of water recharged annually. Recharge in the Sonoma Valley is the result of rain falling on and streams flowing across recharge areas. Recharge from rainfall equals the total rainfall minus runoff and evapotranspiration, and varies from year to year. Recharge is greatest on flat, permeable soils, which allow greater infiltration. At present, data are not sufficient to accurately determine the average annual recharge of the Sonoma Valley. A program to determine


T7N
T6N
R5W
R6W
R7W
Kenwood
Lawndale
Glen Ellen
Boyes
Hot Springs
Moon
Valley
S O N O M A
Sonoma
Taylor Mtn
Hogback Mtn
Nunns Canyon



● WELL LOCATION

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY

GROUND WATER LEVEL MONITORING NETWORK

SCALE
KILOMETRES 1 .5 0 1 2 3 4 5
MILES 1 .5 0 1 2 3 4 5

the annual amount of recharge would include measurements of rainfall, streamflow, and soil permeability, and estimates of plant evapotranspiration.

Rainfall is measured by the National Weather Service in the City of Sonoma. Streamflow in Sonoma Creek is measured by a U. S. Geological Survey gaging station at Agua Caliente. Another gaging station was maintained on Sonoma Creek near Kenwood from 1957 to 1973.

Evapotranspiration, while not usually measured directly, can be estimated by measuring evaporation by an accepted method. The volume of water removed by evapotranspiration can then be estimated by comparing the measured rate of evaporation with the rate of evaporation in an area where evapotranspiration is known.

Very general estimates of soil permeability were made by the U. S. Soil Conservation Service for the Soil Survey of Sonoma County (Miller, 1972). These estimates can be refined by conducting permeameter tests on each major soil type.

Determination of Changes in Ground Water Quality

Additional ground water quality data are necessary to update the "extent of sea water intrusion" map drawn by Kunkel and Upson (1960) for the southern Sonoma Valley. These data should be collected from 5 to 10 shallow wells (less than 60 m or 200 ft deep) of known construction within 3 kilometres (2 miles) of the "extent of sea water intrusion" line drawn in 1960 (Figure 13). Monitoring wells should extract water only from alluvial fan deposits (Plate 1). Water samples from these wells should be analyzed in spring and fall for electrical conductivity. Standard mineral analyses should be taken periodically, such as at 5-year intervals. Changes in ground water quality can be monitored and corrective measures taken if necessary.

Additional water quality sampling should be conducted near the one well known to produce water with nitrates exceeding the recommended limit of 45 mg/L of nitrate (5N/5W-18D2) to determine the source and extent of the contamination.

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GLOSSARY

Agglomerate. A pyroclastic volcanic rock containing a predominance of rounded to subangular fragments greater than 32 mm in diameter.

Alluvian Fan Deposit. A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains upon the lowland.

Alluvium. A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water during comparatively recent geologic time.

Anion. A negatively charged ion, e.g., OH^-.

Aquifer. A geologic formation that stores, transmits, and yields significant quantities of water to wells and springs.

Aquifer Continuity. The degree to which ground water stored in one aquifer or portion of an aquifer is able to move into another aquifer or portion of an aquifer.

Brackish. Water that is intermediate in salt content between streams and sea water; neither fresh nor salty.

Breccia. A rock made up of highly angular, coarse, broken fragments.

Cation. A positively charged ion, e.g., H^+.

Chert. A hard, dense siliceous rock of sedimentary origin.

Clay. A term which denotes either (1) particles, regardless of mineral composition, with diameter less than 1/256 mm or (2) a sediment composed primarily of these particles.

Confined. Refers to ground water under sufficient pressure to rise above the aquifer containing it when the aquifer is penetrated by a well. The difference between the water level in a well and the top of the aquifer is the Hydrostatic Head. Confined ground water is also known as Artesian.

Conglomerate. A cemented rock containing rounded fragments corresponding in size to gravel. The consolidated equivalent of gravel.

Connate Water. Water entrapped in the openings between particles of a sedimentary rock at the time the rock was deposited. The water may be derived from either ocean water or land water.

Consolidated. Firm and coherent.

GLOSSARY (continued)

Constant-Rate Pump Test. Test pumping of a water well at a constant rate of discharge while the drop in the ground water level (drawdown) is recorded in the well or a nearby observation well. The drawdown is plotted versus time since pumping began to determine Transmissivity, the rate at which ground water will flow through a unit width of the aquifer.

Continental Deposits. Sedimentary deposits laid down within a general land area and deposited in lakes or streams or by the wind; nonmarine deposits.

Diatomite. An earthy deposit composed of nearly pure silica and consisting of the shells of microscopic plants called diatoms.

Dip. The angle at which a planar feature such as a fault or formation is inclined from the horizontal.

Evapotranspiration (ET). That portion of rainfall or water applied to plants which is returned to the air through direct evaporation or by transpiration of plants.

Fault. A fracture, or fracture zone, along which there has been displacement of the two sides relative to one another. This displacement may be a few centimetres or many kilometres. An Active Fault is one which has had surface displacement within Holocene time (about the last 11,000 years). The inverse of this, that other faults are inactive, is not necessarily true. A Potentially Active Fault is one which shows evidence of displacement during Quaternary time (last 2 to 3 million years).

Fault Plane. The more or less planar surface of a fault along which dislocation has taken place.

Fault Trace. The surface expression of a fault.

Fault Zone. An area along the trace of a large fault consisting of numerous interlacing small faults and/or a confused zone of gouge.

Fold. A bend in rock strata. An Anticline is an upward fold; it influences ground water by inducing flow away from the fold axis. A Syncline is a downward fold; it influences ground water by inducing flow toward the fold axis.

Formation. A geologic term that designates a specific group of beds or strata which have been deposited in sequence one above the other and during a specific period of geologic time.

Gouge. Finely abraded material occurring between the walls of a fault, the result of grinding movement.

Gravel. A term which denotes either (1) particles, regardless of mineral composition, with diameter greater than 2 mm or (2) unconsolidated sediment composed primarily of these particles. Gravel frequently is found as lens-shaped units within sandy deposits.

GLOSSARY (continued)

Greenstone. An altered basic igneous rock of greenish color due to the presence of such minerals as chlorite, hornblende, and epidote.

Ground Water Barrier. A body of material which is impermeable or has only low permeability and which occurs below the land surface in such a position that it impedes the horizontal movement of ground water and consequently causes a pronounced difference in the level of the water table on opposite sides of it.

Ground Water Basin. An area underlain by one or more permeable formations capable of furnishing a substantial supply of acceptable-quality water. Usually, there is little movement of ground water from one basin to another.

Hydraulics. The aspect of engineering that deals with the flow of water or other liquids.

Hydrograph. A graph showing the changes in the water level in a well with respect to time.

Hydrology. The science that relates to the distribution and circulation of naturally occurring water on and under the earth's surface.

Igneous. Rock formed from the solidification of molten material, either at depth or on the ground surface.

Infiltration. The flow or movement of water through the soil surface into the ground.

Interbedded. Occurring between beds, or lying in a bed parallel to other beds of a different material.

Intrusive. Igneous rock which cools and solidifies below the earth's surface.

Limestone. A sedimentary rock consisting chiefly of calcium carbonate.

Marine Deposits. Sedimentary deposits laid down on the floor of the ocean.

Mathematical Model. A computer technique which simulates responses of a ground water basin to changes in recharge and pumping patterns. Used as a tool to predict future water levels.

Metamorphic. Rock which has reformed in the solid state in response to pronounced changes of temperature, pressure, and/or chemical environment and which takes place below the ground surface. A metamorphic rock originally was of a different form; i.e., it originally was igneous or sedimentary.

Methemoglobinemia. A bluish or purplish discoloration (as of skin) due to deficient oxygenation of the blood which can be caused by excessive nitrates in drinking water.

GLOSSARY (continued)

Milliequivalent. A contraction of "equivalents per million"; the units are "milligram equivalents per kilogram" if derived from data expressed ion parts-per-million or "milligram equivalents per litre" if derived from data expressed in milligrams per litre. In analyses expressed in milliequivalents, unit concentrations of all ions are chemically equivalent.

Obsidian. Volcanic glass.

Oxidation. The process of combining with oxygen; rust is a product of oxidation.

Percolation Rate. The rate at which water passes through the fine intersticies in earth materials.

Permeability. The ability of a geologic material to transmit fluids such as water. The degree of permeability depends on the size and shape of the pore space and the extent, size, and shape of their interconnections.

Potable. Suitable for drinking; said of water and beverages.

Recharge. Replenishment of ground water by rainfall, streams, and other sources. Natural Recharge is that recharge which occurs without assistance or enhancement by humans. Artificial Reacharge is that recharge which occurs when people deliberately modify the natural recharge pattern to increase recharge.

Reduction. The process of removing oxygen; the opposite of oxidation.

Saline. Consisting of or containing salts (minerals), the most common of which are potassium, sodium, or magnesium in combination with chloride, nitrate, or carbonate.

Sand. A term which denotes either (1) particles with diameter ranging from 1/16 to 2 mm or (2) a sediment composed primarily of these particles.

Scoria. Material ejected from a volcanic vent. Such material is usually vesicular, dark in color, heavy, and has a partly glassy-partly crystalline texture.

Sedimentary. Said of rocks formed from sediments. Includes such rock types as sandstone, conglomerate, shale, etc.

Serpentinite. A rock consisting almost entirely of the mineral serpentine, which is the alteration product of several types of ultrabasic rocks.

Silt. A term which denotes either (1) particles with diameter ranging from 1/256 to 1/16 mm or (2) a sediment composed primarily of these particles.

Soil. The collection of natural earthy materials on the earth's surface, the lower limit of which is normally the lower limit of biologic activity.

GLOSSARY (continued)

Sorting. The degree of similarity, in respect to some particular characteristic (frequently size), of the component particles in a mass of material.

Specific Yield. As applied to a rock or soil unit, it is the ratio of (1) the volume of water which, after being saturated, will yield by gravity to (2) its own volume. This ratio is expressed as a percentage.

Storage Capacity. The volume of space below the land surface that can be used to store ground water. Total Storage Capacity is the total volume of space that could be used to store ground water. Available Storage Capacity is that volume of the total storage capacity that does not presently contain ground water and is therefore available to store recharged water.

Stream Gaging. The process by which the streamflow or discharge can be determined by measurement of the water level and velocity in the stream.

Sustained Yield. The volume of ground water that can be extracted annually from a ground water basin without causing adverse effects.

Thermal Water. Hot or warm water.

Total Dissolved Solids (TDS). The total quantity of minerals in solution in water, expressed in milligrams per litre.

TRANSCAP. A computer program which determines transmissivity and storage capacity using specific yield data from individual wells. Averaged specific yield data are converted to transmissivities using equations of a curve developed by the DWR investigation of the Livermore and Sunol Valleys (Ford and Hills, 1974). For specific yield values from 3 to 10, the curve is described by the equation:

$$\Delta T = \Delta D \cdot 10^{\left[3.5319 - \frac{7.16288}{|SY| - 0.84}\right]}$$

and for specific yield values greater than 9, by the equation:

where $\Delta T = \Delta D \cdot (100\,|SY| - 500)$
ΔT = incremental transmissivity
ΔD = incremental depth
$|SY|$ = absolute value for average specific yield for a given interval.

Transmissivity. The rate of flow of water through each vertical strip of aquifer of unit width having a height equal to the thickness of the aquifer and under a unit hydraulic gradient.

Tuff. A rock composed of compacted volcanic fragments smaller than 4 mm in diameter.

GLOSSARY (continued)

Unconformity. A surface of erosion that separates younger strata from older rocks; represents a substantial break or gap in the geologic record.

Usable Storage. That volume of the ground water reservoir capable of accepting recharge water.

Water Table. (1) The upper surface of a zone of saturation except where that surface is formed by an impermeable body or (2) locus of points in soil water at which the pressure is equal to atmospheric pressure.

Well Log. A record made by the driller of a water well which lists geologic materials encountered during drilling and information on the construction of the well (such as casing perforations and sanitary seal).

Definitions Modified from the Following Sources:

American Geological Institute, 1976, "Dictionary of Geological Terms". Revised Edition.

California Department of Water Resources, 1975, "California's Ground Water". Bulletin 118.

Ford, R. S., 1975, "Evaluation of Ground Water Resources: Sonoma County". California Department of Water Resources. Bulletin 118-4, Volume 1: "Geologic and Hydrologic Data".

Peters, H. J., 1980, "Ground Water Basins in California". California Department of Water Resources. Bulletin 118-80.

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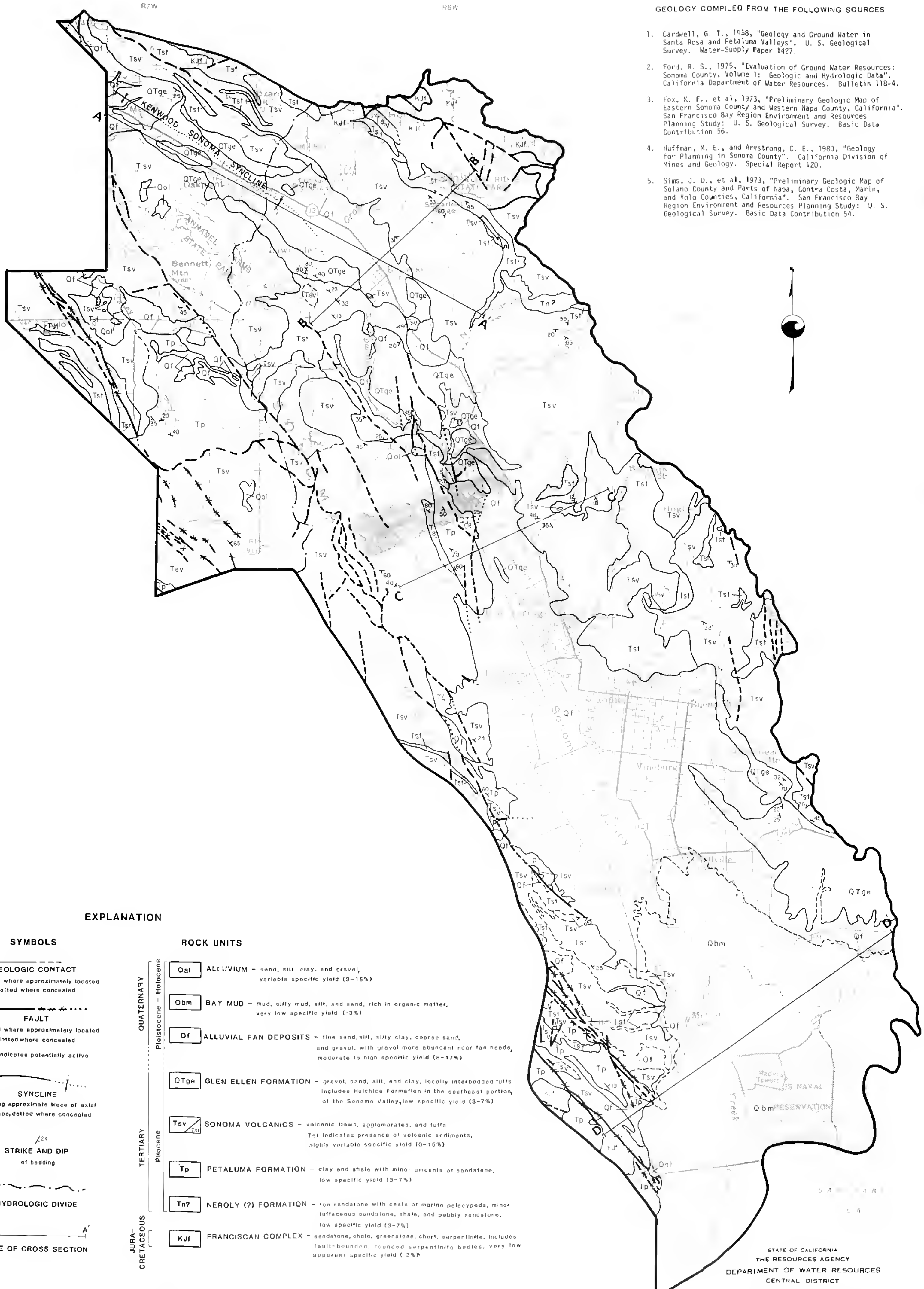
GEOLOGY COMPILE

1. Cardwell, G. T., 1
   Santa Rosa and Pet
   Survey. Water-Sup

2. Ford, R. S., 1975,
   Sonoma County, Vol
   California Departm

PLATE 1



GEOLOGY COMPILED FROM THE FOLLOWING SOURCES:

1. Cardwell, G. T., 1958, "Geology and Ground Water in Santa Rosa and Petaluma Valleys". U. S. Geological Survey. Water-Supply Paper 1427.
2. Ford, R. S., 1975, "Evaluation of Ground Water Resources: Sonoma County, Volume 1: Geologic and Hydrologic Data". California Department of Water Resources. Bulletin 118-4.
3. Fox, K. F., et al, 1973, "Preliminary Geologic Map of Eastern Sonoma County and Western Napa County, California". San Francisco Bay Region Environment and Resources Planning Study: U. S. Geological Survey. Basic Data Contribution 56.
4. Huffman, M. E., and Armstrong, C. E., 1980, "Geology for Planning in Sonoma County". California Division of Mines and Geology. Special Report 120.
5. Sims, J. D., et al, 1973, "Preliminary Geologic Map of Solano County and Parts of Napa, Contra Costa, Marin, and Yolo Counties, California". San Francisco Bay Region Environment and Resources Planning Study: U. S. Geological Survey. Basic Data Contribution 54.

EXPLANATION

SYMBOLS

GEOLOGIC CONTACT dashed where approximately located, dotted where concealed

FAULT dashed where approximately located, dotted where concealed; x indicates potentially active

SYNCLINE showing approximate trace of axial surface, dotted where concealed

STRIKE AND DIP of bedding (24)

HYDROLOGIC DIVIDE

LINE OF CROSS SECTION (A – A')

ROCK UNITS

QUATERNARY	Pleistocene – Holocene	Qal	ALLUVIUM – sand, silt, clay, and gravel, variable specific yield (3-15%)
		Qbm	BAY MUD – mud, silty mud, silt, and sand, rich in organic matter, very low specific yield (-3%)
		Qf	ALLUVIAL FAN DEPOSITS – fine sand, silt, silty clay, coarse sand, and gravel, with gravel more abundant near fan heads, moderate to high specific yield (8-17%)
		QTge	GLEN ELLEN FORMATION – gravel, sand, silt, and clay, locally interbedded tuffs includes Huichica Formation in the southeast portion of the Sonoma Valley; low specific yield (3-7%)
TERTIARY	Pliocene	Tsv / Tst	SONOMA VOLCANICS – volcanic flows, agglomerates, and tuffs. Tst indicates presence of volcanic sediments, highly variable specific yield (0-15%)
		Tp	PETALUMA FORMATION – clay and shale with minor amounts of sandstone, low specific yield (3-7%)
		Tn?	NEROLY (?) FORMATION – tan sandstone with casts of marine pelecypods, minor tuffaceous sandstone, shale, and pebbly sandstone, low specific yield (3-7%)
JURA-CRETACEOUS		KJf	FRANCISCAN COMPLEX – sandstone, shale, greenstone, chert, serpentinite, includes fault-bounded, rounded serpentinite bodies, very low apparent specific yield (3%)

SCALE 1:62,500

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 KILOMETRES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

GEOLOGY OF SONOMA VALLEY
SONOMA COUNTY GROUND WATER STUDY